EUROPEAN SOUTHERN OBSERVATORY

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

# Paranal Science Operations

# MATISSE Template Manual


**Doc. No. ESO-255467**

**Issue 116, Date July 9, 2025**



Prepared C. Paladini, Th. Rivinius, J. Woillez, A. Corporaal, MATISSE IOT . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Date Signature

Approved S. Mieske . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Date Signature

Released A. Kaufer . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .

Date Signature

This page was intentionally left blank

**Change Record**

| Issue/Rev. | Date | Section/Parag. affected | Reason/Initiation/Documents/Remarks |
|---|---|---|---|
| P103 | 11.12.2018 | all | First version for operation |
| P105 | 16.01.2020 | Sect.1.4, 2.3, 2.5, 3.1.2, 3.1.3, 3.1.4, 3.2, 3.2.2, 3.3, 3.5 | Update for P105 P2. |
| P106 | 26.03.2020 | | Addition of GRA4MAT capability |
| P110 | 06.07.2022 | | Unify GRA4MAT templates |
| P112 | 09.08.2023 | | Clarify GRA4MAT capabilities |
| P113 | 01.12.2023 | Sect. 4.2 and 4.5 | GRA4MAT narrow off-axis modifications |
| P114 | 02.08.2024 | Sect. 1, 2, and 4.1 | Clarify detector and instrument configurations |
| P116 | 20.02.2025 | Major updated | GPAO, and GRA4MAT latest performances. |
| P116 | 01.07.2025 | all | NGS keywords and clarifications |

This page was intentionally left blank

# Contents

# 1 Introduction

## 1.1 Scope

This document describes the templates for MATISSE, the second-generation VLTI mid-infrared instrument. As with all VLT instruments, observations are carried out using observation blocks (OBs), which must be defined during Phase-2 preparation via the web-based application p2 or the API. A typical OB consists of an acquisition template an observation template. The user has to select the templates for the instrument mode being requested and defines the values of the template keywords.

Visiting observers at Paranal must also use the web application to prepare their observations. Changes made in p2 in visitor or designator mode are recorded directly in ESO's database and become immediately available at the telescope.

The template manual assumes a basic understanding of MATISSE. Users are encouraged to consult the MATISSE manuals and related web pages.

For details on the VLTI telescope array and adaptive optics, refer to the VLTI User Manual, which provides essential information for successful VLTI observations.

## 1.2 Contact information

In case of questions or suggestions related to Phase-1 and Phase-2 preparation, please contact the ESO User Support Department (`https://support.eso.org`).

## 1.3 ESO observation glossary

- **Constraint Set (CS)**
  List of requirements for the conditions of the observation that is given inside an OB. OBs are only executed if conditions meet or exceed these requirements.

- **Observation Block (OB)**
  An Observation Block is the smallest schedulable entity for the VLT. It consists of a sequence of Templates. Usually, one Observation Block includes one target acquisition template and one or several observation templates.

- **Observation Description (OD)**
  A sequence of templates used to specify the observing sequences within one or more OBs.

- **Observation Toolkit (OT)**
  Tool used to create queues of OBs for later scheduling and possible execution (service mode).

- **Proposal Preparation and Submission (Phase 1)**
  The Phase 1 begins right after the CfP (Call-for-Proposals) and ends at the deadline for CfP. During this period the potential users are invited to prepare and submit scientific proposals. For more information, see:
  `http://www.eso.org/sci/observing/phase1.html`

- **Observation Preparation (Phase 2)**
  Once proposals have been approved by the ESO Observation Program Committee (OPC) and scheduled, users are notified and the Phase 2 begins. In this phase, users are requested to prepare their accepted proposals in the form of OBs using the p2 web application. See:
  https://www.eso.org/sci/observing/phase2.html.

- **Service Mode (SM)**
  In service mode (in contrast to "Visitor-Mode"), the observations are carried out by the ESO Paranal Science-Operation staff (PSO) alone. Observations can be done at any time during the period, depending on the CS given by the user. OBs are put into a queue schedule in OT which later sends OBs to the instrument.

- **Template**
  A template is a sequence of operations to be executed by the instrument. The observation software of an instrument dispatches commands written in templates not only to instrument modules that control its motors and the detector, but also to the telescopes and VLTI sub-systems.

- **Template signature file (TSF)**
  File which contains template input parameters.

- **Visitor Mode (VM)**
  The classic observation mode. The user is on-site to supervise their program execution, to directly analyse the data and to take real-time decisions if necessary.

## 1.4 Period of validity of this manual

This manual is valid for observations with MATISSE and GRA4MAT from **P116** onwards.

## 1.5 Brief description of the offered MATISSE modes

MATISSE is a four-beam interferometric combiner that can operate in the L, M, and N bands simultaneously (i.e. from 3 to 13$\mu$m). It combines the light of either the four Unit Telescopes (UTs) or the four Auxiliary Telescopes (ATs). MATISSE is offered both as standalone instrument (MATISSE standalone) or with GRAVITY as a fringe tracker (GRA4MAT). It is composed of three main parts: the warm optics table (WOP), the L&M-bands cryostat and the N band cryostat. After a dichroic located on the WOP, MATISSE can be seen as two separate instruments working simultaneously (and synchronised). The L&M and the N arms differ in a few points. The most important are:

**Spectral resolutions:**
There are four and two spectral setups for the LM bands and N band, respectively:

- In the L and M bands: LOW (R = 34), MED (R = 506), HIGH (R = 959) (available only in the L band), and HIGH+ ($\sim$ 3666) (available in either the L or M band, but only in GRA4MAT mode). For MATISSE standalone, the central wavelength must be set in either the L or M band to obtain data in the desired spectral range (see Section 4.3.4). A detailed description of the GRA4MAT mode, in which HIGH+ spectral resolution is exclusively available, can be found in Sect. 2.6.1 of the MATISSE User Manual and Woillez, J. et al., 2024, A&A, 688, A190. On the ATs, GRA4MAT with chopping is only possible with the fringe tracker running at a DIT of 0.85 ms.

- In the N band: LOW (R=30) and HIGH (R=218).

**Detectors:**

- The L&M bands cryostat is equipped with a 2048 × 2048 pixels HAWAII-2RG detector (identical to the GRAVITY science detector).
- The N band cryostat is equipped with a 1024 × 1024 pixels AQUARIUS detector (identical to the VISIR detector).

After being spatially filtered by pinholes or slits (in service mode only one pinhole is offered), the light of the four beams is combined in the focal plane and spectrally dispersed. This produces the typical X-lambda fringe pattern, similar to AMBER (Petrov, R.G., et al. 2007, A&A 464, 1). However, in order to efficiently remove background contamination and reduce cross-talk between the fringe peaks, an optical path difference (OPD) modulation is applied on the four beams during observation.

Before the combination, beam splitters can take a part of the flux and redirect it into photometric channels. As these devices are movable, each arm can operate in two different modes:

- SI-PHOT (SImulatenaous PHOTometry): with the beam splitters, the photometric calibration of the fringes is then done during fringe observation.
- HI-SENS (HIgh SENSitivity): In that mode, the beam splitters are removed and all photons are sent to the interferometric channel. Subsequent photometry exposures, closing the shutters one by one, are needed to evaluate the beams absolute photometry.

Currently MATISSE is only offered in a so-called HYBRID mode, where the L&M arm operates in SI-PHOT and the N band in HI-SENS.

### 1.5.1 The beam commuting devices

The Beam Commuting Devices (BCDs) are the first devices in MATISSE. They are two identical devices allowing to commute the beams two by two. BCD1 commutes beams 3&4, and BCD2 beams 1&2. They each have two positions: OUT where the beams are not commuted, and IN where beams are commuted. Following the possible combinations of BCDs OUT and IN, each exposure cycle consists of these four exposures. Commuting the beams allows to remove most instrumental effects, and significantly improves the closure and differential phase measurements.

# 2 Observation Blocks composition

MATISSE OBs come in two flavours that cannot be mixed, corresponding to the offered observing modes: MATISSE standalone and GRA4MAT. As such, MATISSE has two acquisition templates and two observation templates see Table 1. As such, a MATISSE standalone OB will always contain one **MATISSE_img_acq** template followed by one **MATISSE_hyb_obs** template. Similarly, a GRA4MAT OB will contain one **MATISSE_img_acq_ft** template followed by one **MATISSE_hyb_obs_ft** template. In case only correlated flux measurements are obtained for the N band, it is possible to retrieve flux measurements through an additional MATISSE standalone OB, or using photometry from another instrument.

| MATISSE use | Acquisition template | Observation template |
|---|---|---|
| Standalone | **MATISSE_img_acq** | **MATISSE_hyb_obs** |
| GRA4MAT | **MATISSE_img_acq_ft** | **MATISSE_hyb_obs_ft** |

Table 1: Overview of the templates available to prepare MATISSE OBs, organized by MATISSE use (standalone or with GRA4MAT) and template phase (acquisition or observation).

# 3 Acquisition templates

The first template in an OB must be an acquisition template which contains the information to point the telescope at a source, and set up the VLTI and instrument for observation. The templates, their working on the operational side, and the user-required parameters are detailed below.

## 3.1 Template sequence

The sequence of the acquisition template is always the following:

- Telescopes are slewed to the target.
- Delay lines are preset to offer enough delay range for the interferometric observation.
- The adaptive optics loops are closed on the target.

What follows after the AO loop closure depends on whether MATISSE is operated by itself or with the GRAVITY fringe tracker.

### 3.1.1 MATISSE standalone acquisition

When the VLTI is ready, and the lab guiding loop is closed on IRIS, MATISSE can perform additional verifications which are optional:

- The target can be acquired by MATISSE to check the MATISSE-VLTI alignment. As alignment is very stable, this is currently only done once per night, on the first star acquired with the instrument. The night astronomer verifies the instrument, and, if needed (which rarely happens), changes the IRIS reference pixel to align it with MATISSE.
- Though the quality of the pupils in the VLTI lab are checked at the beginning of the night using IRIS, MATISSE also offers an option to verify its pupils internally. This feature is mainly used for technical troubleshooting and is not offered, neither in service nor in visitor mode.

- Finally, a fringe search can be done during the acquisition template. As the VLTI delay line model is now very stable and MATISSE offers a reasonable coherence length even in the L-band low resolution mode (i.e. of the order of 10 $\mu$m) this step is usually only done once per night, during the first acquisition with MATISSE.

Performing MATISSE image acquisition, pupil check, and fringe search is the responsibility of the VLTI night astronomer and is not offered as a user parameter in service mode.

### 3.1.2 MATISSE with GRAVITY fringe tracker acquisition

When MATISSE is operated with the GRAVITY fringe tracker, IRIS is replaced by the acquisition camera of GRAVITY, and the sequence is as follows:

- MATISSE prepares an acquisition OB for a single field off-axis template of GRAVITY. The GRAVITY fringe tracker searches, finds, and tracks the fringes for MATISSE, which then takes the control back.
- The current acquisition procedure requires that MATISSE perform a target acquisition. This step is similar to the one for MATISSE standalone and is also done once per night as the GRAVITY field derotator is static in single off-axis mode. Firstly, MATISSE offsets the internal tip-tilt actuator of GRAVITY to a reference value corresponding to the co-alignment between the two instruments. Then MATISSE the field acquisition and sends the offsets to the GRAVITY tip-tilt mirrors, refining the co-alignment between GRAVITY and MATISSE.
- Then, the GRAVITY acquisition camera takes over the control of the field and aligns itself on the MATISSE position, optimizing the coupling of the target into the fringe tracker fibres, effectively cophasing the instruments.
- MATISSE completes the acquisition sequence with an offset to its internal delay lines, matching the optical path differences of GRAVITY.

The field acquisition on MATISSE, and the fringe acquisition on the GRAVITY fringe tracker, make the acquisition template duration a little longer than for MATISSE standalone. It is responsibility of the VLTI night crew to ensure that the two instruments are aligned and cophased. This is done by observing a calibrator from the observatory queue during twilight every night.

## 3.2 Execution time

MATISSE standalone acquisition template execution times range between 4 min if only the VLTI preset is done, to about 15 min if pupil check with IRIS and image acquisition and fringe search with MATISSE are performed. When operating MATISSE with GRAVITY, the acquisition is always longer at about 15 min. In p2 the execution time is set to 10 min.

## 3.3 GPAO guiding with the UTs

Starting from **P116**, the adaptive optics correction for the UTs is provided either by the GRAVITY+ Adaptive Optics (GPAO). GPAO offers to mode with a natural guide star (NGS) from the optical (GPAO_NGS_VIS) or infrared wavefront sensor (GPAO_NGS_IR), which are located in the Coudé focus of the telescopes. The latter mode, formerly known as CIAO, **is not available for MATISSE so that only GPAO_NGS_VIS can be used on the UTs.** Details on GPAO and CIAO can be found in the VLTI User Manual. Here the key properties of the system are summarised:

- For P116, only the $NGS\_VIS$ mode is offered. The laser guide star (LGS) mode is foreseen for the forthcoming periods.
- The NGS must be fainter than $G_{rp} = -3^m$ and brighter than $G_{rp} = 12.5^m$.
- The guide star can either be the target or an off-axis coudé guide star within a radius of 57.5 arcseconds from a point 10 arcsec east of the target.
- The visual magnitude (faintest, for variable stars) of the coudé guide star should be given in the **"NGS Magnitude"** box, corresponding to the `COU.NGS.MAG` keyword.

The AO system is selected using the `COU.AO.TYPE` keyword in the acquisition template. The default keyword value **"Adaptive Optics mode"** should be `COU.AO.TYPE` = *NGS VIS* if using the NGS.

## 3.4 NAOMI guiding with the ATs

The AT guide by means of the New Adaptive Optics Module for Interferometry (NAOMI). NAOMI is a low-order Shack-Hartman system operating in the visible which replaces the previous STRAP tip-tilt guiding. Installation and commissioning of 4 NAOMI modules took place between September and November 2018. A description of NAOMI and of the limiting magnitudes for the ATs can be found in the VLTI User Manual.

The visual magnitude (faintest, for variable stars) of the coudé guide star should be given in the **"NGS Magnitude"** box, corresponding to the `COU.NGS.MAG` keyword. The details on how to set such keyword are described in Sect. 3.5.2.

As NAOMI is the default guiding system for the ATs, the **"Adaptive Optics mode"** the `COU.AO.TYPE` keyword in the acquisition template should be `COU.AO.TYPE` = *NGS VIS*.

## 3.5 List of user parameters

The two acquisition templates use almost identical keywords. Below a detailed list of the acquisition template parameters defined in p2 is shown. The full list of keywords that are accessible at the telescope, their corresponding ranges, and default values are shown in Tables 6 and 7 for the MATISSE_img_acq and MATISSE_img_acq_ft templates, respectively.

### 3.5.1 Target parameters

**Target parallax**
Parallax of the target in arcsec.

To properly set-up the instrument, its important that the relevant target magnitude and fluxes are set correctly. These are the L and N fluxes for the MATISSE instrument itself, the K band magnitude for IRIS or the GRAVITY fringe tracker. For GRA4MAT the H band magnitude is additionally needed for the GRAVITY acquisition camera.

**L and N band fluxes in Jy**

The object's estimated L and N band fluxes (in Jansky) should be provided in phase 2 (`SEQ.TARG.FLUX.L` and `SEQ.TARG.FLUX.N`). The users can find such flux, for instance, in the Wide-field Infrared Survey Explorer (WISE) all sky catalog. This parameter is used by the instrument to set-up the real-time fringe coherencing parameters. Because of some constraints in the way the phase 1 tool was designed, the user will have to provide the L and N magnitudes and not the flux in phase 1. The MATISSE public page contains a link to a magnitude/flux converter page.

**K band magnitude**

The object estimated K band magnitude (`SEQ.TARG.MAG.K`). This is used by the IRIS lab-guiding system when operating with MATISSE standalone (**MATISSE_img_acq**), or by the GRAVITY fringe tracker with GRA4MAT (**MATISSE_img_acq_ft**).

**H band magnitude**

The object estimated H band magnitude (`SEQ.TARG.MAG.H`). This is only used in GRA4MAT operation (**MATISSE_img_acq_ft**), by the GRAVITY acquisition camera, performing the same function as the IRIS lab-guiding system. If such magnitude is left set erroneously at 0 then a neutral density filter will be inserted in the GRAVITY fringe tracker. The direct effect will be that there is not enough flux in the fiber for fringe tracking.

### 3.5.2 Guide star settings

**Adaptive Optics mode**

This keyword defines the type of coudé guiding to be used. The default setting (i.e. `COU.AO.TYPE` = *NGS VIS*), implies that, for the ATs, NAOMI or, for the UTs, GPAO *NGS VIS* will be used. MATISSE is currently not offered with NGS IR.

**Natural Guide Star (NGS) source**

This keyword is used to tell the system which source shall be used for natural coudé guiding, either: *SCIENCE* if the target is used for the guiding, or *SETUPFILE* if an off-axis natural guide star will be used. In that case, the coudé guide star properties need to be specified as detailed below.

If *SETUPFILE*, the user has to provide the following keywords. These keywords can be left to the default if the `COU.NGS.SOURCE` = *SCIENCE*.

- **NGS Name**
  Target name of the coudé guide star.
- **NGS RA**
  Right Ascension of the natural coudé guide star.
- **NGS Dec**
  Declination of the natural coudé guide star.

- **NGS Parallax**
  Parallax of the natural coudé guide star in arcsec.
- **NGS PM in RA**
  Alpha coordinate of the proper motion of the natural coudé guide star in arcsec/year.
- **NGS PM in Dec**
  Delta coordinate of the proper motion of the natural coudé guide star in arcsec/year.
- **NGS Epoch**
  Epoch of the coordinates of the coudé guide star if it is different from the science target. Usually 2000.

**NGS Magnitude**
Coudé guide star visual magnitude (`COU.NGS.MAG`). This should always be specified. In the case of a variable star the faintest magnitude should be given. For both the ATs and UTs users are encouraged to use guide-star magnitudes obtained in the *Gaia* $G_{rp}$ filter when possible. If nor G nor R magnitude are available, V-band magnitude is also possible, however the users should be careful with the V-band magnitudes because the limiting magnitudes offered are the G-band (see VLTI User Manual).

#### 3.5.3 Interferometric array specifications

**Interferometric Array**
Users will have to specify the interferometric array using generic names instead of specific baselines. The possibilities for MATISSE on the ATs are *small, medium, large, extended*, or a combination of them. For the UTs the only choice is *UTs*. Such baselines as chosen by the user will be logged in the Fits header under ISS BASELINE. However after observations the keyword ISS STATION will specify the actual position of the telescopes, the latter is the keyword that should be used for scientific exploitation.

**Types of interferometric observations**
As of P105 for all VLTI instruments, including MATISSE, users will have to specify the type of interferometric observations. The possibilities for MATISSE are *snapshot, imaging*, or *time-series*. For details, see the VLTI configuration page and Sect. 5 of the VLTI User Manual.

## 4 Observation templates

Following the acquisition template, the user has to include one or more observation templates in the OB. For **P116**, MATISSE offers two main observation templates: the HYBRID observation template for MATISSE standalone **MATISSE_hyb_obs**, and the HYBRID observation template with Fringe Tracker **MATISSE_hyb_obs_ft**.
These templates define an observation in HYBRID mode, where the L&M-band arm observes with the beam splitter in SI-PHOT mode and the N-band arm without the beam splitter in HI-SENS mode.

## 4.1 Template sequence

Here we describe the MATISSE observing sequence for the HYBRID mode, which is the only mode offered for **P116**. The fringe acquisition is similar for MATISSE standalone and for GRA4MAT.

- The MATISSE observation starts with two 30s sky exposures: one recorded with both BCDs in OUT position and a second one with both in IN position. The sky offsets `SEQ.SKY.OFFS.ALPHA` and `SEQ.SKY.OFFS.DELTA` are user parameters that should be modified only for very extended object. The sky exposures are recorded simultaneously on both the HAWAII-2RG and the AQUARIUS detectors.

- The instrument then records a series of fringe exposures simultaneously on both detectors. Each exposure lasts 60s and the total number of exposures is 4 times the **Number of exposure cycles** specified in the template by the user (`SEQ.FRINGES.NCYCLES`). The default exposure cycle is 1. This can be increased to 2 keeping in mind that the concatenation should not last longer than 1h for a CAL-SCI sequence, and 1.5h in the CAL-SCI-CAL. Each cycle consists of 4 exposures taken with different BCD positions: IN-IN, OUT-IN, IN-OUT, OUT-OUT. In service mode, the standard number of cycles is 1 in **LOW, MED, and HIGH resolution.**

  - In the case of **GRA4MAT narrow off-axis observations**, the next relative offset from the given lists specified in `SEQ.OFFS.ALPHA` and `SEQ.OFFS.DELTA` are applied at the start of each BCD cycle. It is important to note that the offsets in the template are cumulative, i.e., always relative to the actual current position, and not absolute against the original pointing. In contrast to what is listed in the template, the header of the final data product file gives the absolute offsets against the original pointing.

- After the fringe sequence, the template can perform a photometry sequence if the template parameter **Do photometry sequence** (`SEQ.PHOTO.ST`) is set to "T". This sequence is necessary to compute visibilities in the N-band, moreover commissioning results showed that the photometry step is crucial to properly calibrate M-band data, and also L-band for sources with L fluxes less than 25 Jy on the ATs and 1.5 Jy on the UTs (see also Sect. 4.4.1 and the MATISSE User Manual). The photometry sequence consists of a four-shutter sequence performed twice, with two BCDs positions (IN-IN and OUT-OUT). Each of the 8 exposure is 60s. The photometry sequence is performed using chopping. The chopping parameters are fixed in service mode (chopping frequency is 1 Hz and stroke is 4.0" in the North-South direction). During the N-band photometry sequence the L&M-band detector records a chopped fringe exposure, that will be treated by the pipeline to provide additional L&M-band data.

## 4.2 Execution time

The total execution times of standard observation OBs, executing the acquisition + observing templates, are the following:

- 20 min with L&M-band in LOW or MED without photometry sequence

- 25 min with L&M-band in HIGH and HIGH+ without photometry sequence

The photometry sequence lasts 10 additional minutes.

## 4.3 MATISSE instrumental and detector configurations

Tables 2-5 summarize the MATISSE instrumental and detector configurations available for observation for **P116** (both for VM and SM). It is advisable when preparing phase 1 and phase 2 of the observations to always double check the instrument webpage News section for last minute information. Note that not all values are offered in service mode and that some are even unavailable in visitor mode. In the below subsections more details on the configuration settings are given.

| Device | Possible values | | comments |
|---|---|---|---|
| | L&M bands | N band | |
| Spatial Filter | 1, **1.5**, 2.0 $\lambda$/D<br>1x5, 1.5x5, 2.0x5 $\lambda$/D | 1.5,**2.0**, 2.5 $\lambda$/D<br>1.5x5, 2.0x5, 2.5x5 $\lambda$/D | Holes or Slits.<br>Fixed to bold value in service |
| Beam Splitter | HI-SENS (Out)<br>**SI-PHOT** (In) | **HI-SENS** (Out)<br>SI-PHOT (In) | Fixed to bold value in service<br>(see Sect. 1.5) |
| Spectral Filter | L-, L, LM, M | N-, N+ | LM bands automatically set depending on $\lambda_0$ |
| Frame Mode | SCI-FAST-SPEED<br>SCI-SLOW-SPEED | SCI-HIGH-GAIN | For L&M band depends on the target brightness |
| Spectral Disp. | LOW (R=34)<br>MED (R=506)<br>HIGH (R=959)<br>HIGH+ (R=3666) | LOW (R=30)<br>HIGH (R=218) | Set by users |
| DIT [s] | 0.02, 0.075, 0.111<br>0.6, 1.3, 3.0, 5.0, 10.0 | 0.02 / 0.075 | Set by users |

Table 2: MATISSE instrumental and detector configurations available for observation.
Note: Elements in blue are only offered with GRA4MAT.

### 4.3.1 Spatial filtering

In each cryostat, spatial filtering is done by pinholes or slits mounted on a motorized wheel. The pinholes diameters and slit widths varies from 1.0 to 2.0 $\lambda$/D in L&M and 1.5 to 2.5 $\lambda$/D in N. All slits have a length of 5 $\lambda$/D. The possible settings are given in Table 2 where we highlight also the service mode configurations.

### 4.3.2 Spectral filters

The four L&M arm and the two N arm spectral filters are positioned on motorized wheels. They are set automatically as per the value of the `SEQ.DIL.WL0` for the L&M arm. Both N- and N+ are used for N band observations. The corresponding transmission curves can be found in the MATISSE user manual.

### 4.3.3 Frame rate modes in L&M band

Unlike the AQUARIUS detector used for the N-band which is offered only in HIGH-GAIN frame mode (Table 3), the L&M-bands HAWAII-2RG detector is offered in two frame-modes for science observations:

| Spectral mode | Frame-mode | DIT (s) | Spectral band ($\mu$m) | Offered in Service |
|---|---|---|---|---|
| LOW | SCI-HIGH-GAIN | 0.020 | 8 - 13[(a)] | **Yes** |
| HIGH | SCI-HIGH-GAIN | 0.075 | 8 - 13 | **Yes** |

Table 3: N band offered configurations for **P116** in service and visitor mode. (a) The low spectral resolution data are rather noisy longward than 11 $\mu$m. Users interested in data with low spectral resolution at such wavelength range may consider to apply for high spectral mode using DIT 0.075, and rebin a posteriori the data to low. This applies only for sources brighter than 35 Jy in N-band.

- SCI-SLOW-SPEED: Full frame detector readout in 1.38s (shorter when windowed)
- SCI-FAST-SPEED: Full frame detector readout in only 0.078s (shorter when windowed)

The major difference between the two modes is the detector read-out noise which is 6 times higher in the SCI-FAST-SPEED mode. For that reason, most objects should be observed in SCI-SLOW-SPEED. The SCI-FAST-SPEED mode is only offered for the brightest targets (limits are listed in Table 4), and should only be used for targets that would saturate the detector using the minimum DITs offered in SCI-SLOW-SPEED. For example, in LOW spectral resolution, the windows including the full L&M bands can be read in 0.020s in SCI-FAST-SPEED mode and 0.111s in SCI-SLOW-SPEED mode. Using the SCI-FAST-SPEED mode allows to observe stars 10 times brighter than the saturation limit in SCI-SLOW-SPEED mode. The saturation limits for all offered modes are given in Table 4 (i.e. column Max Flux). Note that the science target and the calibrators must be observed with the same frame-mode and DIT, so that faint calibrators should be avoided for very bright science targets that require observation in SCI-FAST-SPEED mode.

#### 4.3.4 Spectral dispersion, DITs and wavelength coverage

For N band, the user only needs to set the spectral resolution parameter and the other parameters will be computed by the template accordingly.

For the L&M-bands arm, the user needs to provide: the spectral resolution, the detector frame-mode, the DIT, and the central wavelength of observation $\lambda_0$. Tables 4 and 5 provide a summary of the spectral dispersion, DITs, and the corresponding wavelength coverages for MATISSE standalone and GRA4MAT, respectively.

GRA4MAT can only chop with the fringe tracker running in mode 1 or 2, i.e., at a DIT of 0.85 ms. This holds for targets with correlated $K < 7$ mag and $K < 11$ mag for the ATs and UTs, respectively and must be respected for chopping to be possible (see Sect. 4.4.2).

| Spectral mode | Frame mode | DIT [s] | Coverage [$\mu$m] | Min/Max flux limits [Jy] ATs | UTs | Offered in Service |
|---|---|---|---|---|---|---|
| MATISSE Stand-alone mode (**MATISSE_hyb_obs**) | | | | | | |
| LOW | SCI-FAST-SPEED | 0.020 | 2.85 - 5.0 | 100 / 8000 | 20 / 400 | **Yes** |
| | SCI-SLOW-SPEED | 0.111 | 2.85 - 5.0$^{(a)}$ | 1 / 2000 | 0.06 / 100 | **Yes** |
| | SCI-SLOW-SPEED | 0.075 | 2.85 - 4.2$^{(b)}$ | 1 / 1600 | 0.06 / 80 | **Yes** |
| | SCI-SLOW-SPEED | 0.075 | 4.00 - 5.0 | 2 / 2000 | 0.5 / 100 | **Yes** |
| MED | SCI-FAST-SPEED | 0.075 | 2.85 - 5.0 | 150 / - | 15 / 5000 | **Yes** |
| | SCI-SLOW-SPEED | 0.111 | $\lambda_0 \pm 0.08$ | $\star$ / - | $\star$ / 3000 | **Yes** |
| HIGH | SCI-FAST-SPEED | 0.075 | 2.85 - 4.2 | 500 / - | 50 / 10000 | **Yes** |
| | SCI-SLOW-SPEED | 0.111 | $\lambda_0 \pm 0.04$ | 75 / - | 8 / 6000 | **Yes** |

Table 4: L&M-bands arm offered configurations for MATISSE stand-alone in **P116** in both service and visitor mode. (a) This wavelength coverage is obtained by setting $\lambda_0 = 4.1$ in p2. See also Sect. 4.3.4. (b) This wavelength coverage is obtained by setting $\lambda_0 = 3.5$ in p2. ($\star$) The minimum flux depends on the band of observation. See the table with the absolute and relative measurements limits in the MATISSE instrument webpage. The saturation limits are intended as L band.

When operating in the more sensitive SCI-SLOW-SPEED detector mode, short DITs limit the detector readout window size. This has an implication on the L&M band spectral coverage for a given spectral resolution for MATISSE standalone and for GRA4MAT in HIGH/HIGH+ mode.

The parameter controlling the windowing is the central wavelength (`SEQ.DIL.WL0`). In service mode the wavelength is selected through the **predefined central wavelengths for L&M bands** list depending on the mode and spectral resolution[1] which is also available on the MATISSE instrument webpage. The two values of `WL0` (or $\lambda_0$) allowed in **low spectral resolution are with MATISSE standalone are** :
– 3.5 $\mu$m for observations with DIT 0.075s, allowing to cover the full L-band [2.8, 4.2] $\mu$m;
– 4.1 $\mu$m for observations with DIT 0.111s, allowing to cover the full LM band [2.8, 5] $\mu$m.

To observe several spectral windows in either MED and HIGH resolution, the user can concatenate several observation templates with various values of $\lambda_0$ in the same OB (visitor mode only). In visitor mode the user is free to choose any central wavelength by filling the **user central wavelength** field in p2. This is allowed because depending on the source some spectral features might be red-shifted. The free choice of $\lambda_0$ by the user has a consequence in terms of automatic calibration of the data during the night: it is very likely that visitors will not see their data automatically reduced by the "quick-look MATISSE pipeline" running in Paranal. The pipeline needs in fact a set of standard master calibrations to run, and the master calibrations are usually updated once a year. Master calibrations include only the files for standard modes offered in service mode. The number of non-standard setups for which we prepare (on best effort basis) the pipeline for automatic processing during the night is limited to 2. If 2 visiting astronomers are sharing nights, only 1 setup per astronomer will be reduced. The visiting astronomers have to provide their setup information on the day of their arrival on Paranal. The calibration files needed to reduce the non standard setup are triggered at the end of the night, and will be always available the day after the observations in the ESO archive.

[1] Users interested in observing specific features missing from the service mode current central wavelength list are encouraged to contact the instrument scientist. The list of offered wavelengths can be updated from one observing period to the other.

| MATISSE GRA4MAT mode (**MATISSE_hyb_obs_ft**) | | | | | | | |
|---|---|---|---|---|---|---|---|
| Spectral mode | DIT[(a)] [s] | $\lambda_0$ band | Coverage [$\mu$m] | Min flux limits [Jy] ATs | UTs | Max flux[(b)] [Jy] UTs | Offered in Service |
| LOW | 0.111 | LM ($\lambda_0$=4.1) | 2.85 - 5.0 | 0.2 / 0.7 | 0.01 / 0.07 (L/M) | 38 | Yes |
| MED | 1.3 | LM ($\lambda_0$=4.1) | 2.85 - 5.0 | 1 / 11 | 0.3 / 1 (L/M) | - | Yes |
| MED | 0.6 | L ($\lambda_0$=3.5) | 2.85 - 4.1 | 1 | 0.3 | - | Yes |
| MED | 0.6 | M ($\lambda_0$=4.1) | 4.0 - 5.0 | 11 | 1 | - | Yes |
| HIGH | 1.3 | L ($\lambda_0$=3.5) | 2.95 - 3.5 | 2 | 0.7 | 421 | Yes |
| HIGH+[(b)] | 0.6 | L ($\lambda_0$=4.05) | 3.97 - 4.11 | 20 | 6 | - | Yes |
| | 1.3 | M ($\lambda_0$=4.78) | 4.56 - 5.14 | 17 | 6 | - | Yes |

Table 5: L&M-bands arm offered configurations for GRA4MAT in **P116** in both service and visitor mode. The frame mode is SCI-SLOW-SPEED for all spectral resolutions. (a) The DIT corresponds to the minimum DIT to readout the spectral window indicated in the coverage column. (b) The spectral coverage cuts for HIGH+ results from the drop of the transmission of the HIGH+ GRISM at wavelengths $< 4\,\mu$m. The exact spectral coverage depends on the defined $\lambda_0$.
The minimum flux depends on the band of observation and the turbulence constraints. See the table with the absolute and relative measurements limits in the MATISSE instrument webpage.
[(b)] The **saturation limits** with GPAO on the UTs depend on the spectral mode and DIT as follows:
- LOW LM - 10 Jy with DIT=0.6s.
- LOW LM - 38 Jy with DIT=0.111s.
- HR L - 421 Jy with DIT=1.3s.
- HR L - 55 Jy with DIT=10s.

In **GRA4MAT** mode, by stabilizing the MATISSE fringes, allows much longer DITs and significantly helps with the simultaneous wavelength coverage. The exact $\lambda_0$ is therefore less constraining. Covering the full LM-band is only possible in LOW (with a minimum DIT of 0.111s) and MED (with a minimum DIT of 1.3s). Due to overlapping dispersion orders, HIGH and HIGH+ resolutions cannot cover simultaneously the L and M bands. In HIGH resolution, only the full L-band is covered, with a minimum DIT of 1.3s. In HIGH+, either the L-band (from 3.97 to 4.11 $\mu$m), with a minimum DIT of 0.6s, or the full M-band, with a minimum DIT of 1.3s, can be covered. A further increase of the DIT is possible such that the thermal background dominates the detector readout noise. Background limited DITs are dependent on the spectral mode as follows: 0.6s for LOW, 3.0s for MED, 5.0s for HIGH, and 5-10s for HIGH+. Constraints like dispersion-induced fringe jumps or the need to collect a few DITs per standard 1 min exposures, favour DITs shorter than 10s. DITs as long as 10s should be considered only in low pwv conditions ($<$ 5mm).

## 4.4 On photometry and coherencing

### 4.4.1 Should I perform a photometry sequence?

The photometry is needed to compute visibility in the N-band. Moreover, commissioning results have shown that only chopped interferograms can be used for targets fainter than L = 25 Jy on the ATs, fainter than L = 1.5 Jy on the UTs, and for M-band visibilities. As a consequence it is strongly recommended to always include the N-band photometry step. The

N-band photometry can be skipped only in three cases:

- scientific interest is limited to the N-band, and the target is too faint to acquire N-band photometry (i.e. only N-band correlated flux is required);
- scientific interest is limited to the L-band and both the source and the calibrator are brighter than 25 Jy on the ATs (1.5 Jy on the UTs);
- only (relative) correlated flux measurements are needed.

Experience with VLTI/MIDI showed that for faint objects (for example AGNs), the photometry is the major source of noise and most users prefer to work with correlated flux only.

**The up-to-date sensitivity limits for correlated flux and visibility measurements are given on the MATISSE instrument webpage.**

### 4.4.2 What if I really need absolute visibilities with GRA4MAT?

In GRA4MAT mode, chopping is only supported if the fringe tracker operates in mode 1 or 2, i.e., at a DIT of 0.85 ms. It is limited by the fringe recovery time meaning that slower fringe tracker operations cannot support chopping. In practice, chopping is supported for targets with $K < 7$ mag and $K < 11$ mag for the ATs and UTs, respectively. When the target is too faint to yield absolute visibilities without chopping and correlated fluxes are not sufficient, this can be circumvented by taking a non-GRA4MAT OB immediately after. This is possible because the reconfiguration of the VLTI between different modes is very short and automatic. However, since there are constraints in service mode operations w.r.t. the structure and length of an observation (i.e. the fixed structure of 1h for CAL-SCI, and 1.5h for CAL-SCI-CAL), this is only possible in visitor mode.

### 4.4.3 About MATISSE coherencing

Only one of the two bands (L or N) is used for coherencing during the fringe exposures. It is set by the "**Master band for the coherencing**" user parameter.

In most cases, the L-band should be chosen as the master band, because:

- The L-band sensitivity is higher than the N-band one. There is a factor of about 10 in the fringe detection in L compared to N for the same flux.
- The stellar flux is usually higher in L. For stars there's typically a factor 8 in flux between the bands.

However, the N band might be chosen as master band if:

- the object is over resolved in the L band (V<0.01)
- the object is highly reddened or has a very strong infrared excess (flux in N is 10 times higher than flux in L).

If the user is not sure which band to use, L band should be selected and a note might be added as OB comment and in the README file to let the VLTI night crew decide when acquiring the target.

If the N band is chosen as the master-band, the chopped fringes acquired in the L&M bands during the N-band photometry sequence will be coherenced using the L-band.

## 4.5 List of user parameters

The parameters of the observation templates of the two templates are almost identical. The keyword values requested from the user in p2 are detailed below. The full list of keywords that are accessible at the telescope, their corresponding ranges, and default values are shown in Tables 8 and 9 for the MATISSE_hyb_obs and MATISSE_hyb_obs_ft templates, respectively.

### 4.5.1 Detector setup

**Integration time for the L&M detector**

The detector integration time (DIT) in seconds for the HAWAII-2RG detector used in the L and M bands (`DET1.DIT`). The possible DITs depends on the detector frame mode. **For MATISSE standalone, DITs of 0.020s, 0.075s and 0.111s are currently offered; in addition, DITs of 0.6s, 1.3s, 3s, 5s, and 10s are offered with GRA4MAT.**

**Frame mode for the L&M detector**

Either SCI-SLOW-SPEED or SCI-FAST-SPEED (only for very bright targets; see Sect. 4.3.3 for more information).

**Central wavelength for the L&M bands**

This parameter is used only in SCI-SLOW-SPEED mode where the whole detector cannot be read during one DIT. It specifies the central wavelength of the observing window. In LOW spectral resolution it is only used to specify whether the user wants to observe in the L, M, or both L and M bands. In MED resolution, the spectral window for the standard DIT of 0.111s is of the order of 0.16$\mu$m and in HIGH of 0.08$\mu$m (see also Sect. 4.3.4). In Service Mode the user must choose the central wavelength from the predefined list. In visitor mode the user can enter the central wavelength in the user central wavelength entry of p2.

**Spectral mode for the L&M bands**

MATISSE offers four spectral resolutions in the L&M bands: LOW (R=34), MED (R=506), HIGH (R=959) and HIGH+ (R=3666). The HIGH+ mode is only offered with GRA4MAT.

**Spectral mode for the N band**

MATISSE offers two spectral resolution in the N band: LOW (R=30) and HIGH (R=218).

### 4.5.2 Template setup

**Number of exposure cycles**

This parameter determines the number of fringe exposures cycles. One exposure is one minute and a full cycle is made of 4 exposures. We advice to increase the number of cycles to increase the precision of the measurements in cases where no photometry sequence (i.e. no absolute visibility) is required. The user should keep in mind that the total length of the concatenation should be within a maximum of 1 hour for CAL-SCI and 1.5 hours for CAL-SCI-CAL. Longer concatenations are not allowed in service mode.

**Relative offset in RA and DEC (i.e. GRA4MAT narrow field off-axis offset list)**
Right ascension and declination offsets vs. the GRAVITY fringe tracking source in milliarcseconds (`SEQ.OFFS.ALPHA` and `SEQ.OFFS.DELTA`). The offsets list is cumulative, i.e., the final absolute offset is the sum of all previous relative offsets. Each offset has to be smaller than 5000 mas in either direction, and the accumulated offset has to be within 1 (for UTs) or 3 (for ATs) arcseconds of the original pointing position. The offsetting sequence is performed in the correlated flux phase and during the BCD sequence. The sequence should always end with a return to zero offsets. See also the web documentation.

**Do photometry sequence (T or F)**
If set to "T", a chopped shutter sequence is performed after the fringes exposures in the N-band. During this eight-exposures sequence (4 exposures each in BCD IN-IN and OUT-OUT), the L-band arm records chopped fringe exposures. Note that this photometric exposure is mandatory to obtain visibilities in the N band. If set to "F" the MATISSE pipeline will only be able to deliver correlated flux in the N band. The photometry step is crucial to properly calibrate M-band data and also L-band data for sources fainter than 25 Jy on the ATs and 1.5 Jy on the UTs (see Sect. 4.4.1 for more information). The photometry step **is currently not offered with GRA4MAT narrow field off-axis mode**.

**Sky offset, right-ascension**
Right ascension offset for the sky in arcseconds (`SEQ.SKY.OFFS.ALPHA`). Default is set to 1". This should only be modified in case of a very extended object.

**Sky offset, declination**
Declination offset for the sky in arcseconds (`SEQ.SKY.OFFS.DELTA`). Default is set to 15". This should only be modified in case of a very extended object.

**Master band for the coherencing (L or N)**
Spectral band that will be used to perform the fringe coherencing. Possible values are "L" or "N". The default is L band as the SNR is usually higher on this band. This parameter can be changed at runtime by the night astronomer if coherencing can be better performed in the other band. When operating with GRA4MAT, this option should be kept to L (see Sect. 4.4.3 for more information).

**Observation type**
SCIENCE for the science target and CALIB for the interferometric calibrators.

# 5 MATISSE sensitivity

The target flux limits for MATISSE Stand-alone **can be found on the MATISSE ESO webpage.** They are defined in such a way that the typical errors for:

- Low resolution observations will be better than 5 degrees on closure phase data and better than 10% on absolute visibilities
- Medium resolution observation will be better than 10 degrees for closure phase data and better than 20% on absolute visibilities
- Attempting to obtain absolute calibrated quantities with high resolution is not recommended unless the targets are very bright.
- The uncertainties of medium and high resolution observations will be about 1 degree on differential phases, and better than 10% on differential visibilities.

However, bad observing conditions do not only diminish the flux. If a science case is critically dependent on achieving the smallest possible error bars, it is strongly recommended to request good observing conditions regardless of the target brightness. Observations at seeing values worse than 1.15" (corresponding to Turbulence $>$ 70% and $\tau_0$ greater than 2.2 ms) are not recommended. The user should refer to MATISSE ESO webpages for the sensitivity definitions of GRA4MAT.

# A Comprehensive list of template parameters

## A.1 Acquisition templates

All the acquisition template parameters, including those that cannot be defined by the user in p2 but can be modified at the time of observation, are listed in Tables 6 and 7.

### A.1.1 MATISSE_img_acq

| Name | description | range | default |
|---|---|---|---|
| DET1.READ.CURNAME | Frame mode for L detector | SCI-FAST-SPEED SCI-SLOW-SPEED | SCI-SLOW-SPEED |
| SEQ.ACQ.ST | Do image acquisition | T F | F |
| SEQ.TARG.FLUX.L | L band flux [Jy] | - | 3000 |
| SEQ.TARG.FLUX.N | N band flux [Jy] | - | 300 |
| SEQ.TARG.MAG.K | K-band magnitude | - | 0 |
| SEQ.FS.DET1.DIT | Integration time for fringe-search, L-band | - | 0.111 |
| SEQ.FS.INS.DIL.NAME | Dispersive element for fringe-search, L-band | HIGH+ HIGH MED LOW | MED |
| SEQ.FS.INS.DIN.NAME | Dispersive element for fringe-search, N-band | LOW HIGH | LOW |
| SEQ.FS.INS.SFL.NAME | Spatial filter for fringe-search, L-band | 1.00 1.50 2.00 0.66x5.5 1.50x5.5 2.50x5.5 | 1.5 |
| SEQ.FS.INS.SFN.NAME | Spatial filter for fringe-search, N-band | 1.50 2.00 2.50 1.00x5 1.50x5 2.00x5 | 2.0 |
| SEQ.FS.SKY.DURATION | Duration of sky exposure for fringe-search | 1..60 | 15 |
| SEQ.FS.ST | Do fringe-search | T F | F |
| SEQ.OSF.AUTO | Automatic execution of OSF scripts? | T F | T |
| SEQ.PRESET.ST | Preset VLTI ? | T F | T |
| SEQ.SKY.OFFS.ALPHA | sky offset, right-ascension | - | 1 |
| SEQ.SKY.OFFS.DELTA | sky offset, declination | - | 15 |
| SEQ.TRACK.BAND | Master-band controlling the VLTI delay-lines | L N | L |
| SEQ.CHOP.ST | Use telescope chopping | F T | T |
| TEL.TARG.ALPHA | Target RA | ra | 0 |
| TEL.TARG.DELTA | Target DEC | dec | 0 |
| TEL.TARG.PARALLAX | Target parallax | -1..1 | 0 |
| TEL.TARG.EQUINOX | Target Equinox | -2000..3000 | 2000 |
| TEL.TARG.ADDVELALPHA | Differential tracking in RA ["/s] | -15..15 | 0 |
| TEL.TARG.ADDVELDELTA | Differential tracking in DEC ["/s] | -15..15 | 0 |
| TEL.TARG.PMA | Proper motion in RA ["/yr] | -500..500 | 0 |
| TEL.TARG.PMD | Proper motion in DEC ["/yr] | -500..500 | 0 |
| TEL.GS1.ALPHA | RA of guide star | ra | 0 |
| TEL.GS1.DELTA | DEC of guide star | dec | 0 |
| TEL.CHOP.FREQ | Chopping frequency (Hz) | - | 0.5 |
| TEL.CHOP.POSANG | Azimuth angle of chopping | 0..360 | 0 |
| TEL.CHOP.PVRATIO | Star/sky dwell ratio | 1 | 1 |
| TEL.CHOP.THROW | Amplitude angle of chopping | 0..4.5 | 4.5 |
| COU.NGS.ALPHA | RA of guide star if SETUPFILE | ra | 0 |
| COU.NGS.DELTA | DEC of guide star if SETUPFILE | dec | 0 |
| COU.NGS.PARALLAX | Parallax of guide star if SETUPFILE | -1..1 | 0.0 |
| COU.NGS.EPOCH | Natural guide star epoch if SETUPFILE | -2000..3000 | 2000 |
| COU.NGS.MAG | Magnitude of natural guide star in $G_{rp}$ | -3..25 | 0 |
| COU.NGS.SOURCE | Natural guide star source | SETUPFILE SCIENCE | SCIENCE |
| COU.NGS.PMA | Natural coude guide star proper motion Alpha ["/yr] | -15..15 | 0 |
| COU.NGS.PMD | Natural coude guide star proper motion Delta ["/yr] | -15..15 | 0 |
| COU.AO.TYPE | Guiding Type | DEFAULT NGS_VIS NGS_VIS_TCCD | DEFAULT |
| DEL.FT.SENSOR | Fringe tracker sensor | MATISSE | MATISSE |
| ISS.BASELINE | Interferometric arrays | small medium large extended UTs | - |
| ISS.VLTITYPE | Types of interferometric observations | snapshot imaging time-series | - |

Table 6: Comprehensive list of MATISSE_img_acq template parameters accessible during observation.

### A.1.2 MATISSE_img_acq_ft

| Name | description | range | default |
|---|---|---|---|
| DET1.READ.CURNAME | Frame mode for L detector | SCI-FAST-SPEED SCI-SLOW-SPEED | SCI-SLOW-SPEED |
| SEQ.ACQ.ST | Do image acquisition | T F | F |
| SEQ.TARG.FLUX.L | L band flux [Jy] | - | 3000 |
| SEQ.TARG.FLUX.N | N band flux [Jy] | - | 300 |
| SEQ.TARG.MAG.K | K-band magnitude | - | 0 |
| SEQ.TARG.MAG.H | H-band magnitude | - | 0 |
| SEQ.FS.DET1.DIT | Integration time for fringe-search, L-band | - | 0.111 |
| SEQ.FS.INS.DIL.NAME | Dispersive element for fringe-search, L band | HIGH+ HIGH MED LOW | MED |
| SEQ.FS.INS.DIN.NAME | Dispersive element for fringe-search, N band | LOW HIGH | LOW |
| SEQ.FS.INS.SFL.NAME | Spatial filter for fringe-search, L band | 1.00 1.50 2.00 0.66x5.5 1.50x5.5 2.50x5.5 | 1.5 |
| SEQ.FS.INS.SFN.NAME | Spatial filter for fringe-search, N band | 1.50 2.00 2.50 1.00x5 1.50x5 2.00x5 | 2.0 |
| SEQ.FS.SKY.DURATION | Duration of sky exposure for fringe-search | 1..60 | 15 |
| SEQ.FS.ST | Do fringe-search | T F | F |
| SEQ.OSF.AUTO | Automatic execution of OSF scripts? | T F | T |
| SEQ.PRESET.ST | Preset VLTI ? | T F | T |
| SEQ.SKY.OFFS.ALPHA | sky offset, right-ascension | - | 1 |
| SEQ.SKY.OFFS.DELTA | sky offset, declination | - | 15 |
| SEQ.TRACK.BAND | Master-band controlling the VLTI delay-lines | L N | L |
| SEQ.CHOP.ST | Use telescope chopping | F T | T |
| SEQ.COPHASE.band | Band to cophase in | L N | (L) |
| SEQ.COPHASE.DET1.DIT | Cophasing DIT of LM arm | - | 0.111 |
| SEQ.COPHASE.DET2.DIT | Cophasing DIT of N arm | - | 0.075 |
| SEQ.COPHASE.INS.DIL.NAME | Cophasing resolution of LM arm | - | MED |
| SEQ.COPHASE.INS.DIN.NAME | Cophasing resolution of N arm | - | HIGH |
| SEQ.COPHASE.INS.SFL.NAME | Spatial filter for cophasing, L band (L/D) | - | 1.50 |
| SEQ.COPHASE.INS.SFN.NAME | Spatial filter for cophasing, N band | - | 2.0 |
| SEQ.COPHASE.ST | Do cophasing? | T/F | F |
| TEL.TARG.ALPHA | Target RA | ra | 0 |
| TEL.TARG.DELTA | Target DEC | dec | 0 |
| TEL.TARG.PARALLAX | Target parallax | -1..1 | 0 |
| TEL.TARG.EQUINOX | Target Equinox | -2000..3000 | 2000 |
| TEL.TARG.ADDVELALPHA | Differential tracking velocity in RA ["/s] | -15..15 | 0 |
| TEL.TARG.ADDVELDELTA | Differential tracking velocity in DEC ["/s] | -15..15 | 0 |
| TEL.TARG.PMA | Proper motion in RA ["/yr] | -500..500 | 0 |
| TEL.TARG.PMD | Proper motion in DEC ["/yr] | -500..500 | 0 |
| TEL.GS1.ALPHA | RA of guide star | ra | 0 |
| TEL.GS1.DELTA | DEC of guide star | dec | 0 |
| TEL.CHOP.FREQ | Chopping frequency (Hz) | - | 0.5 |
| TEL.CHOP.POSANG | Azimuth angle of chopping | 0..360 | 0 |
| TEL.CHOP.PVRATIO | Star/sky dwell ratio | 1 | 1 |
| TEL.CHOP.THROW | Amplitude angle of chopping | 0..4.5 | 4.5 |
| COU.NGS.ALPHA | RA of guide star if SETUPFILE | ra | 0 |
| COU.NGS.DELTA | DEC of guide star if SETUPFILE | dec | 0 |
| COU.NGS.PARALLAX | Parallax of guide star if SETUPFILE | -1..1 | 0.0 |
| COU.NGS.EPOCH | Natural guide star epoch if SETUPFILE | -2000..3000 | 2000 |
| COU.NGS.MAG | Magnitude of natural guide star in $G_{rp}$ | -3..25 | 0 |
| COU.NGS.SOURCE | Natural guide star source | SETUPFILE SCIENCE | SCIENCE |
| COU.NGS.PMA | Natural coude guide star proper motion Alpha ["/yr] | -15..15 | 0 |
| COU.NGS.PMD | Natural coude guide star proper motion Delta ["/yr] | -15..15 | 0 |
| COU.AO.TYPE | Guiding Type | DEFAULT NGS_VIS NGS_VIS_TCCD | DEFAULT |
| DEL.FT.SENSOR | Fringe tracker sensor | GRAVITY | GRAVITY |
| ISS.BASELINE | Interferometric arrays | small medium large extended UTs | - |
| ISS.VLTITYPE | Types of interferometric observations | snapshot imaging time-series | - |

Table 7: Comprehensive list of MATISSE_img_acq_ft template parameters accessible during observation.

## A.2 Observation templates

All the observation template parameters, including those that cannot be defined by the user in p2 but can be modified at the time of observation, are listed in Tables 8 and 9.

### A.2.1 MATISSE_hyb_obs

| Name | description | range | default |
|---|---|---|---|
| DET1.READ.CURNAME | Frame mode for L detector | SCI-FAST-SPEED SCI-SLOW-SPEED AUTO | SCI-SLOW-SPEED |
| DET1.DIT | Integration time for L-band | - | 0.075 |
| INS.DIL.NAME | Dispersive element in L-band | HIGH+ HIGH MED LOW | LOW |
| INS.DIN.NAME | Dispersive element in N-band | LOW HIGH | LOW |
| INS.SFL.NAME | Spatial filter in L-band | 1.00 1.50 2.00 0.66x5.5 1.50x5.5 2.50x5.5 | 1.5 |
| INS.SFN.NAME | Spatial filter in N-band | 1.50 2.00 2.50 1.00x5 1.50x5 2.00x5 | 2.0 |
| SEQ.DIL.WL0 | Central wavelength of LM-band spectra | 2.85 -5 | 3.5 |
| SEQ.FRINGES.NCYCLES | Number fringe exposure cycles | - | 1 |
| SEQ.FRINGES.BCD.SEQ | BCD sequence | 2STEPS 4STEPS | 4STEPS |
| SEQ.OSF.AUTO | Automatic execution of OSF scripts? | T F | T |
| SEQ.SKY.OFFS.ALPHA | sky offset, right-ascension | - | 1 |
| SEQ.SKY.OFFS.DELTA | sky offset, declination | - | 15 |
| SEQ.CHOP.ST | Use telescope chopping | F T | T |
| SEQ.PHOTO.ST | Do photometry sequence | T F | T |
| SEQ.TRACK.BAND | Master-band controlling the VLTI delay-lines | L N | L |
| SEQ.TRACK.ST | SEQ.TRACK.ST | T F | T |
| TEL.CHOP.FREQ | Chopping frequency (Hz) | - | 0.5 |
| TEL.CHOP.POSANG | Azimuth angle of chopping | 0..360 | 0 |
| TEL.CHOP.PVRATIO | Star/sky dwell ratio | 1 | 1 |
| TEL.CHOP.THROW | Amplitude angle of chopping | 0..4.5 | 4.5 |
| DPR.CATG | Observation type | SCIENCE CALIB | CALIB |

Table 8: Comprehensive list of MATISSE_hyb_obs observation template parameters accessible during observation.

### A.2.2 MATISSE_hyb_obs_ft

| Name | description | range | default |
|---|---|---|---|
| DET1.READ.CURNAME | Frame mode for L detector | SCI-FAST-SPEED SCI-SLOW-SPEED AUTO | SCI-SLOW-SPEED |
| DET1.DIT | Integration time for L-band | - | 0.6 |
| INS.DIL.NAME | Dispersive element in L-band | HIGH+ HIGH MED LOW | LOW |
| INS.DIN.NAME | Dispersive element in N-band | LOW HIGH | LOW |
| INS.SFL.NAME | Spatial filter in L-band | 1.00 1.50 2.00 0.66x5.5 1.50x5.5 2.50x5.5 | 1.5 |
| INS.SFN.NAME | Spatial filter in N-band | 1.50 2.00 2.50 1.00x5 1.50x5 2.00x5 | 2.0 |
| SEQ.DIL.WL0 | Central wavelength of LM-band spectra | 2.85 -5 | 3.5 |
| SEQ.FRINGES.NCYCLES | Number fringe exposure cycles | - | 1 |
| SEQ.FRINGES.BCD.SEQ | BCD sequence | 2STEPS 4STEPS | 4STEPS |
| SEQ.OSF.AUTO | Automatic execution of OSF scripts? | T F | T |
| SEQ.OFFS.ALPHA | GRA4MAT narrow off-axis offset list, RA [mas] | $-5000, +5000$ | 0 |
| SEQ.OFFS.DELTA | GRA4MAT narrow off-axis offset list, dec [mas] | $-5000, +5000$ | 0 |
| SEQ.SKY.OFFS.ALPHA | sky offset, right-ascension | - | 1 |
| SEQ.SKY.OFFS.DELTA | sky offset, declination | - | 15 |
| SEQ.CHOP.ST | Use telescope chopping | F T | T |
| SEQ.PHOTO.ST | Do photometry sequence | T F | T |
| SEQ.TRACK.BAND | Master-band controlling the VLTI delay-lines | L N | L |
| SEQ.TRACK.ST | SEQ.TRACK.ST | T F | T |
| TEL.CHOP.FREQ | Chopping frequency (Hz) | - | 0.5 |
| TEL.CHOP.POSANG | Azimuth angle of chopping | 0..360 | 0 |
| TEL.CHOP.PVRATIO | Star/sky dwell ratio | 1 | 1 |
| TEL.CHOP.THROW | Amplitude angle of chopping | 0..4.5 | 4.5 |
| DPR.CATG | Observation type | SCIENCE CALIB | CALIB |

Table 9: Comprehensive list of MATISSE_hyb_obs_ft observation template parameters accessible during observation.