



# EUROPEAN SOUTHERN OBSERVATORY

Organisation Européenne 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 GRAVITY Template Manual

Doc. No. ESO-287122

Issue 109b, Date 2022-05-06

Prepared . . . . . Gravity IOT . . . . . 2022-05-06 . . . . .  
Date Signature

Approved . . . . .  
Date Signature

Released . . . . .  
Date Signature

This page was intentionally left blank

### Change Record

Issue/Rev.	Date	Sect. / Paragr. affected	Remarks
098.0	2016-04-30		Document created
099.0	2016-12-01	all	Acquisition template split for SF and DF
099.1	2017-01-31	Tables 1 & 2	
100.0	2017-07-12	all	Complete revision of the document
100.1	2017-08-01	all	Correction of typos and outdated information
101.0	2017-12-15	all	Added CIAO off-axis, <code>COU.AG.TYPE</code> keyword and the swapping template
102.0	2018-06-30	all	Changes to several keywords; added NAOMI
103.0	2018-11-30	2.2 & 3.2	Added the dither template and <code>SEQ.HWPOFF</code>
104.0	2019-07-02	all	Added dual-field on-axis mode and ISS keywords
106.0	2020-05-26	all	Several keywords updated, inserted figures
109.0	2022-04-26	all	Added dual-field wide mode and information on the metrology laser settings.

This page was intentionally left blank

## Contents

<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1	Scope	1
1.2	Contact information	1
1.3	Period of validity of this manual	1
1.4	Glossary	1
1.5	Modifications for P109b	2
<b>2</b>	<b>GRAVITY TEMPLATES</b>	<b>2</b>
2.1	Observing modes	3
2.2	Acquisition templates	4
2.2.1	Which star is which in single-field mode?	4
2.2.2	Which star is which in dual-field mode?	4
2.2.3	Which star is which in dual-field wide mode?	5
2.2.4	Proper motion and parallax	5
2.2.5	MACAO or CIAO guiding with the UTs	5
2.2.6	NAOMI guiding with the ATs	6
2.2.7	Science and fringe-tracking K magnitudes	6
2.2.8	Field guiding H-band magnitude	7
2.2.9	Selecting the polarisation mode	7
2.2.10	Selecting the science combiner resolution	7
2.2.11	Fringe-tracker	7
2.2.12	Dual-field mode	8
2.2.13	Dual-field wide mode	9
2.3	Observing templates	9
2.3.1	Integration time	10
2.3.2	Execution time	12
2.3.3	Acquisition camera frames	13
2.3.4	The swapping template	14
<b>3</b>	<b>TEMPLATE KEYWORDS</b>	<b>15</b>
3.1	Acquisition templates	15
3.1.1	GRAVITY_dual_acq.tsf	15
3.1.2	GRAVITY_dual_wide_acq.tsf	16
3.1.3	GRAVITY_single_acq.tsf	17
3.1.4	GRAVITY_dual_acq_dither.tsf	17
3.1.5	Acquisition keywords	18
3.2	Observing templates	20
3.2.1	GRAVITY_dual_obs_exp.tsf	20
3.2.2	GRAVITY_dual_obs_calibrator.tsf and GRAVITY_single_obs_*.tsf	20
3.2.3	Observing keywords	21
3.2.4	GRAVITY_dual_obs_swap.tsf	21

# 1 INTRODUCTION

## 1.1 Scope

This document describes the observing templates for the 2nd generation VLTI instrument GRAVITY. This document should be used for preparing GRAVITY observations starting with period P109b. Like with other VLT instruments, observations with GRAVITY are carried out making use of **observation blocks** (OBs). The OBs must be created by the user during Phase 2 preparation either with the **p2 web application** or with the **Phase 2 Application Programming Interface (API)**. An OB is a set of observing templates that describe and detail the target acquisition and the data recording. The user has to define the values of the template **keywords** (parameters).

The Template Manual requires the user to have some basic understanding of the GRAVITY instrument. If you are a first time user, we recommend to read the latest GRAVITY User Manual, which can be found on the **GRAVITY Documentation website** at:

<https://www.eso.org/sci/facilities/paranal/instruments/gravity/doc.html>

The OBs are prepared with the web application p2. The p2 web interface is available at:

<https://www.eso.org/p2>

Also visiting observers at Paranal are asked to prepare their observations with this web-based application. OBs created or changed through p2 will be directly recorded in ESO's database and immediately become available at the telescope on Paranal.

The Phase 2 API allows to create, modify, or delete OBs in an automatised way and is hence useful to programmatically produce or modify a large amount of OBs (e.g. for a Large Programme).

Finally, the VLTI User Manual needs to be consulted for a description of those parts of the interferometer which are not instrument specific (e.g. AT configurations, limiting magnitudes for field guiding, VLTI observation types etc.) that are required to prepare VLTI observations. The latest VLTI User Manual can be found on the **GRAVITY Documentation website**.

## 1.2 Contact information

In case of questions or suggestions related to the Phase 2 preparation, please contact the ESO User Support Department ([usd-help@eso.org](mailto:usd-help@eso.org)).

## 1.3 Period of validity of this manual

This manual is valid for observations with GRAVITY starting with GRAVITY dual field wide Science Verification in June 2022 and ESO Period 109b beginning on October 1st, 2022.

## 1.4 Glossary

- **Constraint Set (CS)**

List of requirements for the conditions of the observation that is given inside an OB. OBs are only executed under this set of minimum conditions.

- **Observation Block (OB)**

An Observation Block is the smallest schedulable entity for the VLT. It consists of a sequence of templates. Usually, a GRAVITY Observation Block includes one target acquisition and one exposure template. Especially for astrometric observations swapping the fringe-tracker and science targets, however, longer sequences are common.

- **Observation Description (OD)**

A sequence of templates used to specify the observing sequences within one or more OBs.

- **Observation Toolkit (OT)**

A tool used to create queues of OBs for scheduling and possible execution in service mode taking the constraint set (CS) into account.

- **Proposal Preparation and Submission (Phase 1)**

The Phase 1 begins right after the Call for Proposals (CfP) 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>

- **Phase-2 Proposal Preparation (P2)**

Once proposals have been approved by the ESO Observation Program Committee (OPC), 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:

<http://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 his/her program execution, to directly analyse the data and to take real-time decisions if necessary.

## 1.5 Modifications for P109b

For P109b, the following template changes are implemented with respect to the templates from the previous period:

- Information on the dual-field wide template has been added (see Sect. 2.2).

## 2 GRAVITY TEMPLATES

The number of GRAVITY observing templates, is minimal and grouped according to the mode, i.e. either single-field (SF, on-axis fringe-tracking using the science star), dual-field (DF, fringe-tracking using a reference star within the field-of-view), and dual-field wide (DW, fringe-tracking using a reference star picked by the Star Separator system). There are three templates for preset, acquisition and fringe search: one in single-field mode and two in dual-field mode (normal dual-field and dual-field wide). There are two additional templates for the normal dual-field mode: one template which allows to swap the fringe-tracking and science objects (swap template) as well as one template to acquire a source within the range of the Star Separator (STS) systems without presetting the telescopes (dither template). Furthermore there are four templates for fringe observations: two for single-field

mode (science and calibrator) and two for dual-field modes (again science and calibrator). Hence, there are nine observing templates in total. The templates require user-provided input for a limited number of keywords.

## 2.1 Observing modes

A description of the GRAVITY observing modes can be found on the public [GRAVITY web pages](#) for the science users. In summary, the instrument consists of two independent interferometers, the so-called fringe-tracker (FT) and the science spectrometer (SC). The fringe-tracker stabilises the fringes on the science target (in single-field mode) or a nearby fringe-tracking reference star (in dual-field modes). This observing strategy allows longer exposures (significantly longer than the atmospheric coherence time) on the science spectrometer without losing significant fringe contrast. The observing wavelength is for both channels the K-band ( $1.98 - 2.40 \mu\text{m}$ ). The following setups of GRAVITY can be currently used:

- Three distinct field modes: the dual-field (DF), the dual-field wide (DW) and the single-field (SF). In single-field mode the light of a single science target is split 50%-50% between fringe-tracker and the science channel. In dual-field mode, a nearby object (separation to the science target  $d \leq 4''$  for the ATs and  $d \leq 2''$  for the UTs) is used for fringe-tracking. In dual-field wide the VLTI Star Separators are used to allow fringe tracking from a source that is  $d \leq 30''$  from the science target.
- Three spectral setups for the science spectrometer :
  1. Low Resolution  $\mathcal{R} \sim 22$
  2. Medium Resolution  $\mathcal{R} \sim 500$
  3. High Resolution  $\mathcal{R} \sim 4000$

Note, the resolution of the fringe-tracker is fixed at  $\mathcal{R} \sim 22$  and its data are always delivered in the FITS files. Hence, low resolution for the SC spectrometer is normally only used in dual-field. In addition, low resolution is not offered in dual-field wide.

- Two polarisation modes for the fringe-tracker & science spectrometer:
  1. Split polarisation (only linear polarisation)
  2. Combined polarisation

For the best visibility accuracy “split polarisation” is recommended. In case of faint objects and SNR limitations “combined polarisation” is recommended. The polarisation mode has to be the same for fringe-tracker and science spectrometer.

- Telescope configurations of four ATs or four UTs.

Table 2 in Sect. 2.3.2 gives guidelines for DIT values for the science spectrometer. Normally, the fringe-tracker DIT is set automatically based on the object’s **correlated** K-band magnitude, as determined from the total K-band magnitude and visibility.

It should be noted that the adaptive optics units MACAO or CIAO, both on the UTs (see Sect. 2.2.5), or NAOMI on the ATs (see Sect. 2.2.6) are a prerequisite for observations with GRAVITY. For proper adaptive optics (AO) operations, the Coudé guide star must be suitably bright for guiding and should be located closer than  $\sim 15''$  from the science target to ensure a good AO correction. See the [VLTI user manual](#) for details.



## 2.2 Acquisition templates

The first template in an OB must be an acquisition template, which points the telescope at a source and sets up the VLTI and instrument for observations. For GRAVITY, the name of this template is *GRAVITY\_single\_acq*, *GRAVITY\_dual\_acq* or *GRAVITY\_dual\_wide\_acq*. The sequence of these three templates is very similar. They start by a “preset”: the target coordinates  $(\alpha, \delta)$  are sent to the telescopes and the delay lines, so they can slew to the position corresponding to the target coordinates at preset time. Once the VLTI is tracking and Coudé-guiding, the target(s) should be seen on the *Acquisition Camera* of GRAVITY. Internal actuators take care of the field rotation and ensure that the target(s) is/are injected into the fringe-tracker and science channel fibers. In dual-field mode, the internal differential delay lines are preset such that they compensate the differential optical path between the two objects. To ensure a correct compensation of the differential delay, it is advisable to use as accurate offsets from the fringe-tracker source to the science source as possible, at least using coordinates from the same catalogue (e.g. 2MASS). In dual-field wide mode the internal differential delay lines are not used, instead the PRIMA differential delay lines compensate for the differential optical path between the two objects. The final step in the acquisition template is to search and track fringes. The search uses a saw tooth pattern around the nominal fringe position (i.e. zero OPD) with increasing amplitude. As soon as the fringes are found and the control loop is locked the acquisition template is finished and the science exposures defined in the observation template is executed.

In addition to the three standard acquisition templates mentioned above, there is a fourth acquisition template, the *GRAVITY\_dual\_acq\_dither* template, which acts like reduced dual-field acquisition template. It allows offsetting the field within the stroke of the Star Separator (STS) actuator (8" in any direction;  $\sim 20''$  perpendicular to the roof) using the keywords `SEQ.DITHER.X` and `SEQ.DITHER.Y`. The purpose of this template is to allow fast observations of multiple targets within the given range, without sending a full preset to the telescopes. It can only be used if a previous preset has been sent to the telescopes, e.g. using the dual beam acquisition (*GRAVITY\_dual\_acq*). Due to its complexity, the dither template is currently only offered in Visitor Mode.

What follows is a detailed description of some important definitions and parameters of the acquisition templates. The user is advised to read through these subsections in order to create the acquisition template correctly.

As GRAVITY observations may need up to three different objects (telescope Coudé guide star, instrument fringe-track object and instrument science object), the user can find in these three subsections details on how the different objects are defined in the three acquisition template.

### 2.2.1 Which star is which in single-field mode?

In GRAVITY SF mode, the science target and the FT object are the same object. Therefore the SF acquisition template only lists the keywords related to the science object. For standard observations, one can either chose telescope on-axis or off-axis Coudé guiding for the telescope adaptive optics correction. In telescope on-axis guiding, the observation uses only one object to perform the adaptive optics corrections, to track the fringes and to record the science data. If the science target is not bright enough for the adaptive optics system of the telescope, another, off-axis star can be chosen to guide the telescope. This is explained in detail in the VLTI user manual.

### 2.2.2 Which star is which in dual-field mode?

In order to make efficient use of the VLTI field of view of  $4''$  (ATs) and  $2''$  (UTs), GRAVITY DF observations are preset at the telescope to coordinates that correspond to a position in between the FT and SC source. The system does this automatically based on the coordinates and the separation provided in the acquisition template. **The coordinates in the target field are those of the FT object.** This implementation means that the Coudé guiding in dual-field mode is by definition

**always** off-axis. Therefore, the user has to set `COU.AG.GSSOURCE = SETUPFILE` in dual-field mode and provide the properties of the Coudé guide star. In most cases, the Coudé guide star is the same as the FT object as it is usually brighter than the science object both in the optical (for NAOMI/MACAO) and in the near-IR (for fringe-tracking). However the guide star can also be a third object (distance restrictions apply, see the [VLTI user manual](#)) when both the FT and SC objects are too faint for the adaptive optics of the telescope. It is also possible that the target of scientific interest is the Coudé guide star, e.g. when it is much bluer than the FT object and therefore the brighter object in the optical for adaptive optics correction.

### 2.2.3 Which star is which in dual-field wide mode?

For increasing the sky coverage of GRAVITY, in 2022 a new mode GRAVITY dual-field wide has been implemented. This mode uses the Star Separators for picking a science target and a fringe tracker target that are at most separated by  $30''$ . The dual-field wide mode works similarly to the normal dual field mode, except that here **the coordinates in the target field are those of the SC object**. Here, Coudé guide star can be the fringe tracker object (option `COU.AG.GSSOURCE = FT`), science target (option `SCIENCE`), or it can be a third star (option `SETUPFILE`). In most cases, the Coudé guide star is the same as the FT object as it is usually brighter than the science object both in the optical (for NAOMI/MACAO) and in the near-IR (for fringe-tracking). However, the guide star can also be a third object (distance restrictions apply, see the [VLTI user manual](#)) when both the FT and SC objects are too faint for the adaptive optics of the telescope.

### 2.2.4 Proper motion and parallax

The knowledge of the current object coordinates ( $\alpha, \delta$ ) determines the ability to predict the fringe position. For targets with a proper motion larger than 50 mas/year or a parallax greater than 100 mas it is important to provide both values in the acquisition template. If not provided, the fringe search can take significantly longer than normal. For an effective use of the allocated time we request that the known proper motions are incorporated into the OBs.

### 2.2.5 MACAO or CIAO guiding with the UTs

On the Unit Telescopes, adaptive optics correction is provided either by MACAO in the optical or by CIAO in the infrared, both located in the Coudé foci of the telescopes. Note that for the dual-field wide mode CIAO is not available. Details on MACAO and CIAO can be found in the [VLTI User Manual](#), which also includes information on which system to choose for a certain observational setup. Here we list only the main properties of these systems.

MACAO (Multi-Application Curvature Adaptive Optics) is a 60 element curvature adaptive optic system working in the visible. It has the following requirements:

- The guide star must be fainter than  $V = 1^m$  and brighter than  $V = 15^m$ . Note that the Strehl drops significantly in K with a Coudé guide star fainter than  $V = 12^m$ .
- The guide star must be within a radius of 57.5 arcsec from a point 10 arcsec to the East of the science target.
- The faintest (if variable) V magnitude of the Coudé guide star should be given in the keyword `COU.GS.MAG`.

CIAO (Coudé Infrared Adaptive Optics) is an infrared Shack-Hartmann type adaptive optics system and has the following requirements:

- The guide star must be brighter than  $K = 10^m$  in off-axis mode.

- The separation of the guide star from the science target must be between 4 and 60 arcsec for off-axis Coudé guiding with CIAO.
- Seeing  $\leq 1.1$  arcsec and coherence time  $> 1.5$  ms, both at 500 nm.
- CIAO cannot be used in the GRAVITY dual-field wide mode.

The respective AO system is selected using the keyword `COU.AG.TYPE` in the acquisition template. By default (`COU.AG.TYPE = ADAPT_OPT`) MACAO will be used for the UTs, which is equivalent to specifically setting `COU.AG.TYPE = DEFAULT`. For CIAO off-axis guiding, `COU.AG.TYPE` must be set to `IR_AO_OFFAXIS`, with no impact on the sensitivity of GRAVITY. See also Sect. 3.1.

To ensure a good AO correction a distance of  $< 15''$  between the Coudé guide star and the science target is recommended, as otherwise anisoplanatic effects deteriorate the correction. To efficiently inject light into GRAVITY, AO correction must be used. It is not possible under any weather conditions to perform GRAVITY observations without AO correction.

### 2.2.6 NAOMI guiding with the ATs

Since P102, the Auxiliary Telescopes 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 replaced the previous STRAP tip-tilt guiding. Even for the best atmospheric conditions, it is not possible to perform GRAVITY observations without that the telescopes are properly guiding. The requirements for successful NAOMI guiding are the same as previously for STRAP guiding:

- The guide star must be brighter than  $R = 15^m$ . Note however that the tip-tilt correction drops significantly in K for a guide star fainter than 11th magnitude. E.g. when Coudé guiding on a star of  $R = 13^m$ , the K-band limit for fringe-tracking drops by about 1 magnitude.
- The guide star should be within a radius of  $< 15''$  from the science target in order to guarantee a good AO correction: the effective adaptive optics correction drops with distance from the science target, so it is recommended that the user chooses a guide star as close as possible. A rule of thumb is that the magnitude limit of GRAVITY is brighter by 1 magnitude for every  $15''$  from the science object.
- It is requested that the faintest (if variable) R magnitude of the guide star is given in the keyword `COU.GS.MAG`.

The NAOMI units are used by default when observing with the ATs (`COU.AG.TYPE = ADAPT_OPT`). This is equivalent to specifically setting `COU.AG.TYPE = DEFAULT` (see Sect. 3.1).

### 2.2.7 Science and fringe-tracking K magnitudes

In dual-field and dual-field wide mode, the `SEQ.FT.ROBJ.MAG` keyword must be used to specify the **total** K-band magnitude,  $K_{\text{tot}}$ , of the fringe-tracking object. From this the correlated magnitude  $K_{\text{cor}} = K_{\text{tot}} - 2.5 \times \log_{10}(V)$  is calculated using the expected visibility  $V$  on the longest baseline of an “open telescope triplet” (or non-closed triangle for example AT1-AT2, AT2-AT3 and AT3-AT4). This baseline does not have to be the longest baseline of the quadruplet as fringe-tracking will make use of so-called bootstrapping: if one knows the zero-OPD on two of the baselines of a closed triangle then the remaining one can be deduced (e.g. if ZOPD on baseline 12 and 23 are known then the ZOPD on 13 can be deduced). The correlated magnitude  $K_{\text{cor}}$  is used to set up the fringe-tracker (see Sect. 2.2.11). The total K magnitude of the science target should be independently provided using the keyword `SEQ.INS.SOBJ.MAG`.

In single-field mode the **total** K-band fringe-tracking magnitude is equivalent to the science target K-band magnitude. Hence only the keyword `SEQ.INS.SOBJ.MAG` is available in the template *GRAVITY\_single\_acq*.

### 2.2.8 Field guiding H-band magnitude

The `SEQ.FI.HMAG` keyword should be used to specify the uncorrelated H-band magnitude of the science source (in single-field) or the H-band brightest of the two objects (SC or FT) in dual-field. For dual-field wide both H-band magnitudes, SC and FT, have to be defined. The *Acquisition Camera* uses the H-band light for the object acquisition and slow field guiding. In the dual-field wide mode also the H-band magnitude of the science object has to be defined by using the keyword `SEQ.INS.SOBJ.HMAG`. In dual-field wide mode the H-band magnitude of the SC target has to be brighter than H=14mag and H=17mag for ATs and UTs, respectively.

### 2.2.9 Selecting the polarisation mode

Observations can be done in polarisation split or combined mode. In split mode a Wollaston prism is introduced in the beam. It splits the two linear polarisations on the detector. This increases the visibility accuracy as polarisation phase shifts originating from the optical train are separated. The disadvantage however is that the light is spread over twice as many pixels, i.e. the read noise is increased. In case of bright targets (where read noise can be neglected) the split mode is to be preferred. The combined mode should be used in case of faint objects, where read noise dominates the signal to noise. Currently FT and SC have to be in the same polarisation mode. Polarisation split mode can be chosen by setting the keywords `INS.FT.POL` and `INS.SPEC.POL` to *IN*: Wollaston prism inserted. The combined mode is chosen with *OUT*: Wollaston prism out.

### 2.2.10 Selecting the science combiner resolution

In SF and DW two spectral resolutions are offered (medium and high), whereas in DF all three can be chosen. The spectral mode can be selected by setting the keyword `INS.SPEC.RES` to *LOW*, *MED* or *HIGH*. The choice of the spectral resolution depends on whether the observations are in SF or DF, on the target brightness, on the science goals, on the desired visibility accuracy (SNR) and on the available observing time. As a “rule-of-thumb”, the user should consider high resolution (and combined polarisation) only for targets brighter than  $K < 8^m$  on the ATs or  $K < 11^m$  with the UTs. Otherwise the necessary on-source integration time exceeds 1 h for any reasonable SNR. Fainter targets should be observed in medium or low resolution. The reason why low resolution is offered in DF only is that the FT resolution is the same as SC and those SC low resolution in SF would imply duplication of data (as the same polarisation is imposed). DW mode is currently only offered in medium and high resolution.

### 2.2.11 Fringe-tracker

GRAVITY always operates with the internal fringe-tracker. It is not possible to use GRAVITY without this system. Normally, the DIT of the fringe-tracker is automatically selected based on the correlated K-band magnitude,  $K_{\text{cor}}$ , calculated from both the total K-band magnitude,  $K_{\text{tot}}$ , and expected visibility  $V$  specified by the user according to:  $K_{\text{cor}} = K_{\text{tot}} - 2.5 \times \log_{10}(V)$ .

Currently, fringe-tracking is feasible under the following conditions:

- Seeing below  $1.4''$  and  $\tau_0$  above 1.6 ms (that is turbulence  $T \leq 85\%$ ).
- Transparency THN or better.

Table 1: Currently defined fringe-tracker modes. Magnitude ranges are given for the ATs; for the UTs, the same modes apply but for  $3^m$  fainter magnitudes.

FT mode	magnitude range (ATs)	gain	DIT [ms]	Kalman mode
1	$K_{\text{tot}} < 2^m$	low	0.85	2
2	$2^m \leq K_{\text{cor}} < 7^m$	high	0.85	2
7	$7^m \leq K_{\text{cor}} < 9^m$	high	3	2
9	$9^m \leq K_{\text{cor}}$	high	10	2

- Altitude above 30 degrees.
- All AO loops closed and resulting in a Strehl ratio at least 10%.
- Fringe-tracker object fulfilling the limiting correlated magnitude constraints on at least three baselines that do not form a triangle (e.g. 13/23/24, or 12/13/14). These are listed on the [GRAVITY instrument website](#). Then it is possible to boot-strap other baselines with lower visibilities.

In practice, the fringe-tracker mode is normally set up according to the expected correlated magnitude of the fringe-tracking object:  $\text{FT mode} = \text{floor}(K_{\text{cor}} - K_{\text{AT/UT}})$ , where the magnitude is modified by  $K_{\text{AT/UT}}$  which takes the value  $K_{\text{AT/UT}} = 0^m$  when observing with the ATs and  $K_{\text{AT/UT}} = 3^m$  when observing with the UTs, i.e. a certain fringe-tracker mode is activated for  $3^m$  fainter magnitudes on the UTs than for the ATs. The currently available modes of the fringe-tracker and their magnitude ranges are listed in Table 1. This corresponds to the default procedure when  $\text{FT.MODE} = \text{AUTO}$ .

The fringe-tracker can also be forced into a certain mode by setting the keyword  $\text{FT.MODE}$  to one of the available fringe-tracker modes. This may be necessary under certain circumstances, for example because both science target and calibrator should have the same fringe-tracking setup. If the magnitudes are such that the science target and calibrator would lead to different fringe-tracker modes, the calibrator can be forced into the same mode by explicitly setting the mode with the keyword  $\text{FT.MODE}$ . For example for observations with the UTs of a science target in DF with a correlated magnitude of the fringe-tracking object of  $K_{\text{cor}}^{\text{FT}} = 10.2^m$  the corresponding FT mode is 7. An associated calibrator in SF with a correlated magnitude of  $K_{\text{cor}}^{\text{cal}} = 9.3^m$  would imply FT mode 2. To ensure that both the science and calibrator use the same fringe-tracker setup,  $\text{FT.MODE} = 7$  should be set for the calibrator. Note that the fringe-tracker modes are the same for ATs and UTs, but their respective magnitude ranges are shifted by  $3^m$ .

### 2.2.12 Dual-field mode

In dual-field mode, the offset in right ascension and declination in milliarcseconds of the science target relative to the fringe-tracking object has to be provided with the keywords  $\text{SEQ.INS.SOBJ.X}$  and  $\text{SEQ.INS.SOBJ.Y}$ , i.e. the coordinates of the FT source are the reference. As a result, the FT coordinates need to be filled out in the “target” tab of the OB (i.e. the  $\text{TEL.TARG}$  keywords). The binary separation should be as accurate as possible, at least accurate to within 100 mas. If the separation is poorly known the differential delay lines will not preset correctly and the fringes in the science channel will not necessarily be close to 0 OPD. Also, the time to fringe search might increase significantly, i.e. the observing efficiency could be reduced. See also Sect. 2.2.2 for the definition of the FT, SC and Coudé guide objects.

The requirements for the dual-field mode are:

- The science target correlated K-band magnitude must not differ more than  $7^m$  from the fringe-tracker source.

- The separation between fringe-tracker source and science target must be  $< 2.0''$  for the UTs and  $< 4.0''$  for the ATs in order to prevent vignetting of the sources.

There are two set-ups in dual-field mode depending on the distance of the FT and SC objects and whether the UTs or ATs are used. For separations  $< 0.27''$  with the UTs or  $< 1.17''$  with the ATs, the same 50% beam-splitter as in the single-field case is used (“dual-field on-axis”). For larger distances ( $> 0.27''$  with the UTs or  $> 1.18''$  with the ATs),  $\sim 100\%$  of the light of each source are injected into the fibres using a roof-top mirror (“dual-field off-axis”).

### 2.2.13 Dual-field wide mode

In dual-field wide mode the science targets coordinates are given in the “target” tab of the OB. The fringe tracker target parameters on the other hand are defined in the acquisition template `GRAVITY_dual_wide_acq` itself. It is very important to include accurate information on the coordinates and proper motions for both targets.

The requirements for the dual-field wide mode are:

- The fringe tracker target correlated K-band magnitude must be  $< 10.5$  mag and  $< 9.5$  mag for UTs and ATs, respectively.
- The limiting magnitude for the science target depends on the turbulence category and the separation between the science target and fringe tracker target. More information can be found from: [GRAVITY Instrument Description website](#).
- The separation between fringe-tracker source and science target must be  $< 30.0''$  for both the UTs and ATs. This is due to atmosphere anisoplanatism which induces coherence loss with increased separation.
- The science target has to have magnitude  $H < 14$  mag on the ATs and  $H < 17$  mag on the UTs.

Due to the need of good atmospheric conditions (turbulence class 30% and better), observations in service mode are strongly encouraged to optimize the scientific return. Note also that the dual-field wide mode only provides relative measures (differential visibilities and phases), no absolute visibilities, due to atmospheric effects when separation increases. Calibrations of the interferometric transfer function are thus not needed and not offered for this mode.

## 2.3 Observing templates

Following the acquisition template, the user has to chose an observation template. This template is the second and the last one in a normal GRAVITY OB. It is used to record the fringe and sky data. There are currently only four observation templates:

1. single-field science target, `GRAVITY_single_obs_exp`
2. single-field calibrator, `GRAVITY_single_obs_calibrator`
3. dual-field science target, `GRAVITY_dual_obs_exp`
4. dual-field calibrator, `GRAVITY_dual_obs_calibrator`

The templates use almost identical keywords. The appropriate template should be chosen according to the mode (single/dual) and the target (science/calibrator). Dual-field wide uses the same observing template as the normal dual-field observation (`GRAVITY_dual_obs_exp`), however no calibrator observations are offered in this mode.

Table 2: Suggested ranges of the uncorrelated K-band magnitude,  $K$ , of the science object for the various offered DITs of the science combiner when observing with the ATs. Values are given for single-field or dual-field on-axis mode, where the light is split 50%-50% between the SC and FT channels. In dual-field off-axis and in dual-field wide, 100% of the object light reach the science combiner; hence the suggested magnitude ranges are offset by  $\Delta K = 0.7^m$  to fainter magnitudes (e.g. DIT = 0.3 s in combined mode and medium resolution should be used for  $1.7 < K < 3.7$  of the SC object). In turn, for observations using the UTs, the values are offset by  $\Delta K = 3^m$  to fainter magnitudes for on-axis observations and by  $\Delta K = 3.7^m$  for off-axis dual-field observations (e.g. DIT = 3.0 s in split mode, dual-field on-axis and high resolution should be used for  $3.7 < K < 5.7$ ). Note that DIT > 30 s for low spectral resolution is not possible (see text).

DIT [s]	Polarisation	Spectral Resolution (INS.SPEC.RES):		
		<i>LOW</i>	<i>MED</i>	<i>HIGH</i>
0.3	Combined	$4.5 < K < 6.5$	$1.0 < K < 3.0$	$-1.5 < K < 0.5$
1.0	Combined	$5.5 < K < 7.5$	$2.5 < K < 4.5$	$0.0 < K < 2.0$
3.0	Combined	$7.0 < K < 9.0$	$3.5 < K < 5.5$	$1.0 < K < 3.0$
10.0	Combined	$8.0 < K < 10.0$	$5.0 < K < 7.0$	$2.5 < K < 4.5$
30.0	Combined	$9.5 < K < 11.5$	$6.0 < K < 8.0$	$3.5 < K < 5.5$
100.0	Combined	—	$7.5 < K < 9.5$	$5.0 < K < 7.0$
300.0 <sup>1</sup>	Combined	—	$8.5 < K < 10.5$	$6.0 < K < 8.0$
0.3	Split	$4.0 < K < 6.0$	$0.5 < K < 2.5$	$-2.5 < K < -0.5$
1.0	Split	$5.0 < K < 7.0$	$2.0 < K < 4.0$	$-1.0 < K < 1.0$
3.0	Split	$6.5 < K < 8.5$	$3.0 < K < 5.0$	$0.0 < K < 2.0$
10.0	Split	$7.5 < K < 9.5$	$4.5 < K < 6.5$	$1.5 < K < 3.5$
30.0	Split	$9.0 < K < 11.0$	$5.5 < K < 7.5$	$2.5 < K < 4.5$
100.0	Split	—	$7.0 < K < 9.0$	$4.0 < K < 6.0$
300.0 <sup>1</sup>	Split	—	$8.0 < K < 10.0$	$5.0 < K < 7.0$

<sup>1</sup> DIT = 300 s only offered in Visitor Mode

Each template allows a sequence of exposures. The sequence consists of science target exposures (OBJECT) and off-source exposures (SKY). The observing sequence can be defined by the user with the keyword `SEQ.OBSSEQ`. The sequence can contain any combination of object (O) and sky (S) exposures. The `SEQ.SKY.X` and `SEQ.SKY.Y` are used to select the offset of the sky exposure. These offsets will move the GRAVITY internal actuators in the directions given. It is suggested to use offsets of at least 2000 mas to avoid any star light entering the fibres, depending on the atmospheric conditions. Also, make sure that in dual-field the sky offset will not position the SC star on the FT fibre or vice versa. Safest is to offset perpendicular to the binary separation vector.

### 2.3.1 Integration time

The exposure time for the science spectrometer should be chosen according to the mode and **uncorrelated** K-band magnitude of the science target. It is specified by the keyword `DET2.DIT`. Table 2 lists the suggested ranges of K-band magnitudes that can be observed with the different DIT values when using that ATs in on-axis mode (light split 50%-50% between the SC and FT channels). Figure 1 shows the same information in graphical form. For the given magnitude ranges the data will be photon noise limited. For magnitudes brighter / lower than indicated, the detector will become

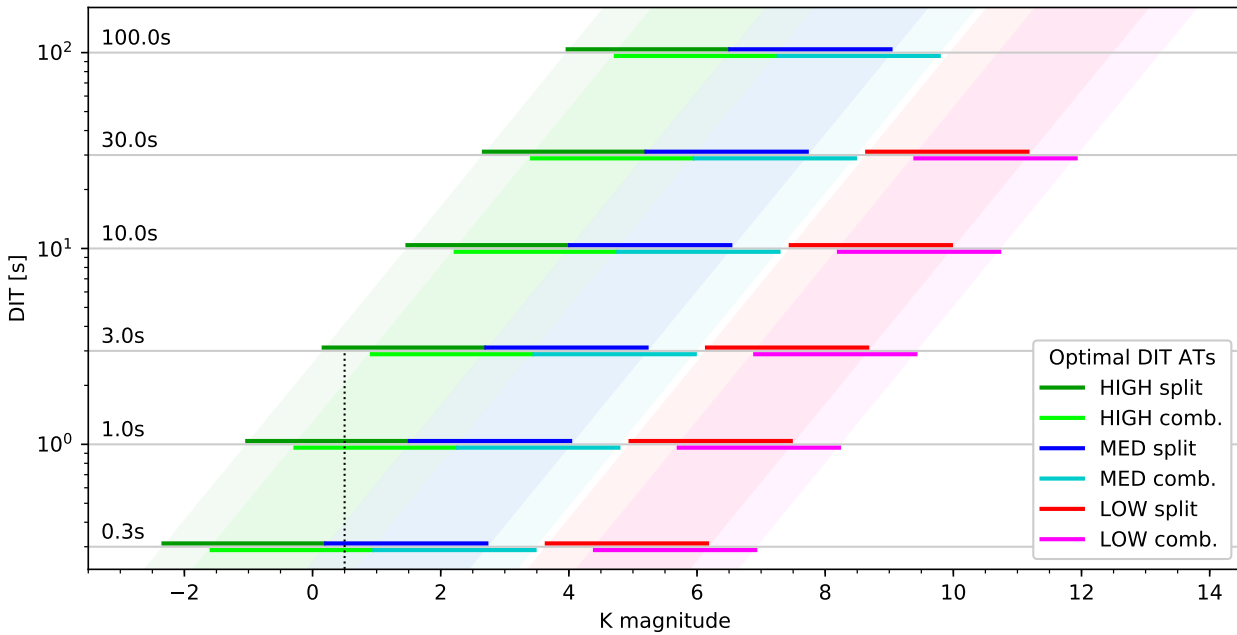


Figure 1: Suggested DIT values for the science combiner, DET2.DIT, for the ATs as a function of the instrument mode and of the K-band magnitude of the science object. The shaded areas show the suggested range of DITs as a function of K-band magnitude, the horizontal lines the actually available DIT values. Values are given for single-field or dual-field on-axis mode, where the light is split 50%-50% between the SC and FT channels. For example for a target with  $K = 0.5^m$  (dotted vertical line), observations can be carried in both high resolution split mode for DET2.DIT = 1 s or 3 s (intersections with dark green lines) and high resolution combined mode for DET2.DIT = 0.3 s or 1 s (light green lines) as well as medium resolution split mode with DET2.DIT = 0.3 s (blue line), c.f. table 2. For the UTs, see Fig. 2.

non-linear and ultimately saturate. For magnitudes significantly fainter / higher, the data will start to become read noise limited. With combined polarisation  $0.5^m$  fainter targets can be observed than with split polarisation as the light is spread over less pixels. In off-axis dual-field and dual-field wide modes 100% light of the science target reaches the science detector, hence the suggested magnitude ranges are offset by  $\Delta K = 0.7^m$  to fainter magnitudes:  $K_{DF} \triangleq K_{SF} + 0.7^m$ , where  $K_{SF}$  are the values listed in table 2. Because of the higher photon collecting power of the UTs, the magnitudes given in table 2 are shifted by  $\Delta K = 3^m$  to fainter magnitudes for on-axis observations and by  $\Delta K = 3.7^m$  for off-axis dual-field observations. That is  $K_{UTs} \triangleq K_{ATs} + 3^m$ . Figure 2 shows the suggested magnitude ranges for the UTs, for the on-axis case.

DITs larger than 30 s saturate the detector in low spectral resolution due to the backscatter of the metrology laser alone. Note that already for  $INS.SPEC.RES = LOW$ ,  $INS.SPEC.POL = COMB$  and  $DIT = 30$  s count rates of  $\sim 20\,000$  ADU are reached from this laser contamination alone. Therefore,  $DIT = 10$  s should be used for low spectral resolution observations of most faint targets.

The number of frames (NDIT) per exposure can be specified with DET2.NDIT.OBJECT for the science exposure and DET2.NDIT.SKY for the sky exposure. See table 3 for recommended NDIT values as function of the DIT and number of exposures. The following requirements apply:

1. The total exposure time ( $DIT \times NDIT$ ) must not exceed 420 s, i.e. 7 min.
2. The number of science frames (NDIT) should be more than 4 and at most 320.

To efficiently remove any incoherent flux and any possible bias of the measurements, the GRAVITY internal piezos are modulated for each exposure of the science detector with a repetitive pattern of 4



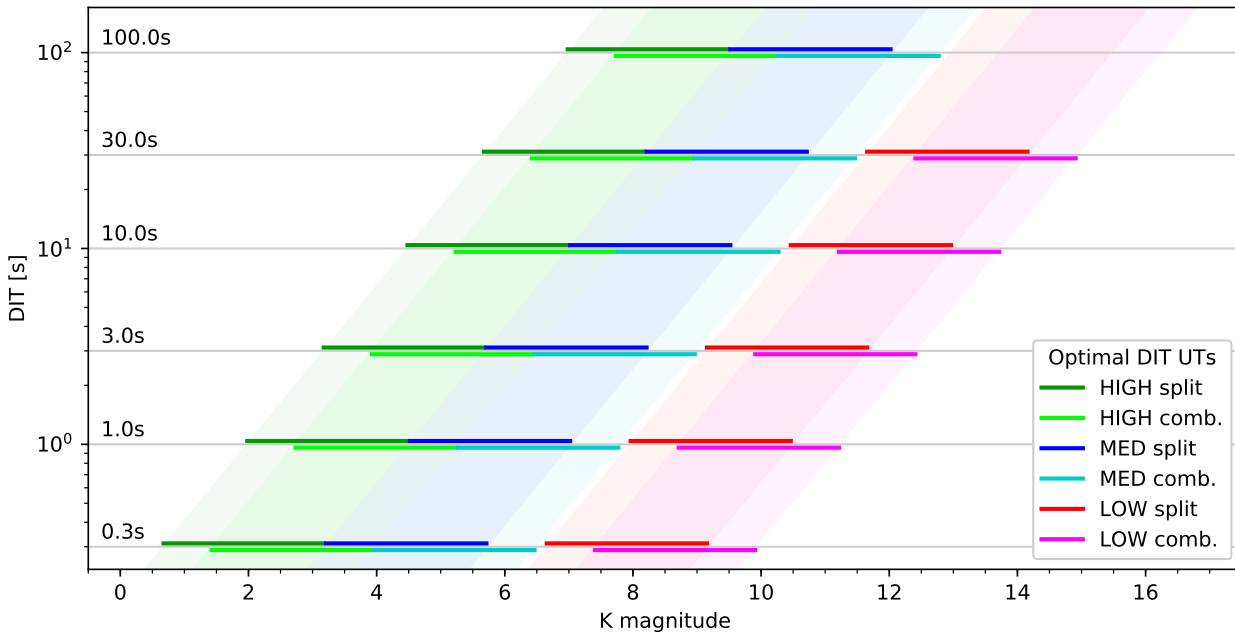


Figure 2: Suggested DIT values for the science combiner, DET2.DIT, for the UTs as a function of the instrument mode and of the K-band magnitude of the science object. Values shown for on-axis observations. That is the same as Fig. 1, but with the magnitudes shifted by  $\Delta K = 3^m$  towards fainter magnitudes.

or 16 exposures (for details, see [Lacour et al. 2019, A&A 624, A99](#)). It is therefore recommended to always use a multiple of 4 in the NDIT, or even better a multiple of 16 for sufficiently short DITs.

### 2.3.2 Execution time

A conservative estimate of a CAL/SCI sequence is one hour. Each acquisition takes roughly 10 min (it can take longer on faint targets). About 20 min have to be spent for object and sky exposures. As the calibrator normally is observed with the same configuration, the total execution time for one calibrated visibility spectrum is 60 minutes (SCI – CAL).

The following model for the calculation of the execution time is applied for SF observations:

$$\text{exectime} = 600 \text{ s} + \text{DIT} \times \text{NDIT} \times \text{NEXP} + 40 \text{ s} \times \text{NEXP} \quad (1)$$

and for DF observations:

$$\text{exectime} = 800 \text{ s} + \text{DIT} \times \text{NDIT} \times \text{NEXP} + 40 \text{ s} \times \text{NEXP}, \quad (2)$$

where NEXP is the number of exposure entered in the observing template keyword `SEQ.OBSSEQ`. For background limited data, the default is to use the same number of NDIT for S(ky) and O(bject).

A typical example on how to fill the 30 minutes would be the following:

One could try to observe an OS sequence in single-field mode; so we have to subtract 600s for the acquisition as well as  $2 \times 40$ s for the merging of the FITS file and offset to / from the sky position. This leaves 1120s for the integration, or 560s seconds for each exposure, which is too long for Service Mode. Instead, aiming at an exposure time of roughly 5 minutes, we better use an OSOO sequence, leaving 1040s, or 260s per exposure. So, for a target with  $K = 3^m$  and observations in medium spectral resolution using the ATs, this would typically mean choosing  $\text{DIT} = 1$  s and  $\text{NDIT} = 256$ , the latter being a multiple of 16 in order to reduce the bias from incoherent flux (see previous section). If on the other hand, observations in high spectral resolution are needed, this would imply  $\text{DIT} = 10$  s, and a sequence of OSOOSO with  $\text{NDIT} = 16$  would optimally fill out the 30 minutes.

Table 3: Overview of DIT and recommended NDIR values for different number of exposures for SF and DF mode as well as the resulting total execution time of the OB (including the acquisition). The value  $\text{DIT} \times \text{NDIT}$  should be less than 420 seconds and the number of science frames (NDIT) must not exceed 320, while the total execution time of the OB should ideally stay below 1800 seconds. NDIR should be a multiple of 4 or better of 16.

DIT	NEXP	NDIT	Exec. time	NDIT	Exec. time
[s]	(O S ..)	SF	SF [s]	DF	DF [s]
0.3	5	320	1280	320	1480
	6	320	1416	320	1616
	7	320	1552	320	1752
	8	320	1688	272	1773
	9	304	1781	224	1765
1.0	2	320	1320	320	1520
	3	320	1680	288	1784
	4	256	1784	208	1792
	5	192	1760	160	1800
	6	160	1800	112	1712
3.0	2	128	1448	128	1648
	3	112	1728	96	1784
	4	80	1720	64	1728
	5	64	1760	48	1720
	6	48	1704	32	1616
10.0	2	32	1320	32	1520
	3	32	1680	16	1400
	4	16	1400	16	1600
	5	16	1600	16	1800
	6	16	1800	12	1760
30.0	2	12	1400	12	1600
	3	12	1800	8	1640
	4	8	1720	4	1440
	5	6	1400	4	1600
100.0	2	4	1480	4	1680
	3	4	1920	4	2120

### 2.3.3 Acquisition camera frames

The internal *Acquisition Camera* is used for the object acquisition as well as slow pupil and tilt guiding. By default each science exposure contains a continuous sequence of acquisition frames ( $\text{DET1.NDIR} = 0$ ) with an integration time  $\text{DIT} = 0.7\text{ s}$ . This means the user obtains H-band images of the science target with roughly  $2''$  (on the UTs) /  $4''$  (on the ATs) field-of-view during the entire integration time. In certain cases the acquisition frames may be scientifically interesting to the user.

### 2.3.4 The swapping template

The swapping template, *GRAVITY\_dual\_obs\_swap*, is only used for dual-field observations. It swaps the fringe-tracking and science objects by rotating the field by  $180^\circ$  using the derotator of GRAVITY. This template can be used for normal science observations, if the user wishes to observe both dual-field objects with spectral resolution (e.g. binary stars, YSOs etc). In this case, the template avoids using a full acquisition and saves observing time. This template is also required for astrometry to obtain an independent metrology zero. However note that the astrometric mode of GRAVITY is currently still under development, meaning that the use of this template for astrometric observations is not fully supported by ESO.

This is a stand-alone template which do not require parameters provided by the user. Similar to an acquisition template, no data is taken during the execution of the swapping template.

A normal observing sequence using the swapping template would hence consist of 4 templates:

- Acquisition (*GRAVITY\_dual\_acq*)
- Science exposure (*GRAVITY\_dual\_obs\_exp*)
- Swap of objects (*GRAVITY\_dual\_obs\_swap*)
- Science exposure (*GRAVITY\_dual\_obs\_exp*; fringe-tracker and science object swapped)

### 3 TEMPLATE KEYWORDS

In the following tables, we give for each template the keywords that have to be set by the user during Phase 2 preparation.

#### 3.1 Acquisition templates

##### 3.1.1 GRAVITY\_dual\_acq.tsf

Parameter	Range ( <i>Default</i> )	Label
SEQ.FT.MODE	AUTO 1 2 7 9 ( <i>AUTO</i> )	Fringe Tracker mode
SEQ.MET.MODE	ON OFF ( <i>ON</i> )	Metrology laser mode
SEQ.FT.ROBJ.NAME	(Name)	FT object name
SEQ.FT.ROBJ.MAG	-10...30 ( <i>0.0</i> )	FT object K band magnitude
SEQ.FT.ROBJ.HMAG	-10...30 ( <i>0.0</i> )	FT object H band magnitude
SEQ.FT.ROBJ.DIAMETER	0...300 ( <i>0.0</i> )	FT object diameter (mas). Only required for <b>calibrator</b> OBs.
SEQ.FT.ROBJ.VIS	0...1 ( <i>1.0</i> )	FT object expected visibility
SEQ.INS.SOBJ.NAME	(Name)	SC object name
SEQ.INS.SOBJ.MAG	-10...30 ( <i>0.0</i> )	SC object K band magnitude
SEQ.INS.SOBJ.DIAMETER	0...300 ( <i>0.0</i> )	SC object diameter (mas). Only required for <b>calibrator</b> OBs.
SEQ.INS.SOBJ.VIS	0...1 ( <i>1.0</i> )	SC object expected visibility
SEQ.INS.SOBJ.X	-60000...60000 ( <i>0.0</i> )	SC object RA offset from FT object in mas
SEQ.INS.SOBJ.Y	-60000...60000 ( <i>0.0</i> )	SC object DEC offset from FT object in mas
TEL.TARG.PARALLAX	-20...20 ( <i>0.0</i> )	FT object parallax (arcseconds)
INS.SPEC.RES	LOW MED HIGH ( <i>MED</i> )	Science spectrometer resolution LOW, MED or HIGH
INS.FT.POL	IN OUT ( <i>IN</i> )	Fringe-tracker polarisation mode split (IN) or combined (OUT)
INS.SPEC.POL	IN OUT ( <i>IN</i> )	Science spectrometer polarisation mode split (IN) or combined (OUT)
COU.AG.TYPE	DEFAULT ADAPT.OPT ADAPT.OPT_TCCD IR_AO_OFFAXIS ( <i>ADAPT.OPT</i> )	Type of Coude guiding
COU.AG.GSSOURCE	SCIENCE FT SETUPFILE ( <i>SETUPFILE</i> )	Coude guide star (GS) input
COU.AG.ALPHA	RA ( <i>00:00:00.000</i> )	GS RA if SETUPFILE
COU.AG.DELTA	DEC ( <i>00:00:00.000</i> )	GS DEC if SETUPFILE
COU.AG.PARALLAX	-20...20 ( <i>0.0</i> )	GS parallax in arcsec
COU.AG.PMA	-10...10 ( <i>0.0</i> )	GS proper motion in RA
COU.AG.PMD	-10...10 ( <i>0.0</i> )	GS proper motion in DEC
COU.GS.MAG	-3...25 ( <i>0.0</i> )	GS G band magnitude
ISS.BASELINE	small medium large astro- metric UTs ( <i>NODEFAULT</i> )	Interferometric Array
ISS.VLTITYPE	snapshot imaging time-series astrometry ( <i>NODEFAULT</i> )	Types of interferometric observations

## 3.1.2 GRAVITY\_dual\_wide\_acq.tsf

Parameter	Range ( <i>Default</i> )	Label
SEQ.FT.MODE	AUTO 1 2 7 9 ( <i>AUTO</i> )	Fringe Tracker mode
SEQ.MET.MODE	ON OFF ( <i>ON</i> )	Metrology laser mode
SEQ.FT.ROBJ.NAME	(Name)	FT object name
SEQ.FT.ROBJ.MAG	-10..30 ( <i>0.0</i> )	FT object K band magnitude
SEQ.FT.ROBJ.HMAG	-10..30 ( <i>0.0</i> )	FT object H band magnitude
SEQ.FT.ROBJ.DIAMETER	0..300 ( <i>0.0</i> )	FT object diameter (mas). Not required.
SEQ.FT.ROBJ.VIS	0..1 ( <i>1.0</i> )	FT object expected visibility
SEQ.FT.ROBJ.ALPHA	0..240000 ( <i>NODEFAULT</i> )	FT object RA
SEQ.FT.ROBJ.DELTA	-900000..900000 ( <i>NODEFAULT</i> )	FT object DEC
SEQ.FT.ROBJ.PARALLAX	-20..20 ( <i>0</i> )	FT object parallax in arcseconds
SEQ.FT.ROBJ.PMA	-10..10 ( <i>0</i> )	FT object proper motion in RA
SEQ.FT.ROBJ.PMD	-10..10 ( <i>0</i> )	FT object proper motion in DEC
SEQ.INS.SOBJ.NAME	(Name)	SC object name
SEQ.INS.SOBJ.MAG	-10..30 ( <i>0.0</i> )	SC object K band magnitude
SEQ.INS.SOBJ.HMAG	-10..30 ( <i>0.0</i> )	SC object H band magnitude
SEQ.INS.SOBJ.DIAMETER	0..300 ( <i>0.0</i> )	SC object diameter (mas). Not required.
SEQ.INS.SOBJ.VIS	0..1 ( <i>1.0</i> )	SC object expected visibility
TEL.TARG.PARALLAX	-20..20 ( <i>0.0</i> )	SC object parallax (arcseconds)
INS.SPEC.RES	MED HIGH ( <i>MED</i> )	Science spectrometer resolution MED or HIGH
INS.FT.POL	IN OUT ( <i>IN</i> )	Fringe-tracker polarisation mode split (IN) or combined (OUT)
INS.SPEC.POL	IN OUT ( <i>IN</i> )	Science spectrometer polarisation mode split (IN) or combined (OUT)
COU.AG.TYPE	DEFAULT ADAPT_OPT ADAPT_OPT_TCCD IR_AO_OFFAXIS ( <i>ADAPT_OPT</i> )	Type of Coude guiding
COU.AG.GSSOURCE	SCIENCE FT SETUPFILE ( <i>FT</i> )	Coude guide star (GS) input
COU.AG.ALPHA	RA ( <i>00:00:00.000</i> )	GS RA if SETUPFILE
COU.AG.DELTA	DEC ( <i>00:00:00.000</i> )	GS DEC if SETUPFILE
COU.AG.PARALLAX	-20..20 ( <i>0.0</i> )	GS parallax in arcsec
COU.AG.PMA	-10..10 ( <i>0.0</i> )	GS proper motion in RA
COU.AG.PMD	-10..10 ( <i>0.0</i> )	GS proper motion in DEC
COU.GS.MAG	-3..25 ( <i>0.0</i> )	GS G band magnitude
ISS.BASELINE	small astrometric UTs ( <i>NODEFAULT</i> )	Interferometric Array
ISS.VLTITYPE	snapshot time-series ( <i>NODEFAULT</i> )	Types of interferometric observations

## 3.1.3 GRAVITY\_single\_acq.tsf

Parameter	Range ( <i>Default</i> )	Label
SEQ.FT.MODE	AUTO 1 2 7 9 ( <i>AUTO</i> )	Fringe Tracker mode
SEQ.MET.MODE	ON OFF ( <i>ON</i> )	Metrology laser mode
SEQ.INS.SOBJ.NAME	(Name)	SC object name
SEQ.INS.SOBJ.MAG	-10...30 ( <i>0.0</i> )	SC object K band magnitude
SEQ.INS.SOBJ.HMAG	-10...30 ( <i>0.0</i> )	SC object H band magnitude
SEQ.INS.SOBJ.DIAMETER	0...300 ( <i>0.0</i> )	SC object diameter (mas). Only required for <b>calibrator</b> OBs.
SEQ.INS.SOBJ.VIS	0...1 ( <i>1.0</i> )	SC object visibility
TEL.TARG.PARALLAX	-20...20 ( <i>0.0</i> )	SC object parallax (arcseconds)
INS.SPEC.RES	LOW MED HIGH ( <i>MED</i> )	Science spectrometer resolution LOW, MED or HIGH
INS.FT.POL	IN OUT ( <i>IN</i> )	Fringe-tracker polarisation mode split (IN) or combined (OUT)
INS.SPEC.POL	IN OUT ( <i>IN</i> )	Science spectrometer polarisation mode split (IN) or combined (OUT)
COU.AG.TYPE	DEFAULT ADAPT.OPT ADAPT.OPT_TCCD IR_AO.OFFAXIS ( <i>ADAPT.OPT</i> )	Type of Coude guiding
COU.AG.GSSOURCE	FT SCIENCE SETUPFILE ( <i>FT</i> )	Coude guide star (GS) input
COU.AG.ALPHA	RA ( <i>00:00:00.000</i> )	GS RA if SETUPFILE
COU.AG.DELTA	DEC ( <i>00:00:00.000</i> )	GS DEC if SETUPFILE
COU.AG.PARALLAX	-20...20 ( <i>0.0</i> )	GS parallax in arcsec
COU.AG.PMA	-10...10 ( <i>0.0</i> )	GS proper motion in RA
COU.AG.PMD	-10...10 ( <i>0.0</i> )	GS proper motion in DEC
COU.GS.MAG	-3...25 ( <i>0.0</i> )	GS G band magnitude
ISS.BASELINE	small medium large astro- metric UTs ( <i>NODEFAULT</i> )	Interferometric Array
ISS.VLTITYPE	snapshot imaging time-series astrometry ( <i>NODEFAULT</i> )	Types of interferometric observations

## 3.1.4 GRAVITY\_dual\_acq\_dither.tsf

Parameter	Range ( <i>Default</i> )	Label
SEQ.DITHER.X	-20000...20000 ( <i>0.0</i> )	FT object dRA offset in mas.
SEQ.DITHER.Y	-20000...20000 ( <i>0.0</i> )	FT object dDEC offset in mas.
SEQ.FT.MODE	AUTO 1 2 7 9 ( <i>AUTO</i> )	Fringe Tracker mode
SEQ.FT.ROBJ.NAME	(Name)	FT object name
SEQ.FT.ROBJ.MAG	-10...30 ( <i>0</i> )	FT object total magnitude
SEQ.FT.ROBJ.DIAMETER	0...300 ( <i>0</i> )	FT object diameter (mas). Only required for <b>calibrator</b> OBs.
SEQ.FT.ROBJ.VIS	0...1 ( <i>1.0</i> )	FT object expected visibility
SEQ.INS.SOBJ.NAME	(Name)	SC object name
SEQ.INS.SOBJ.MAG	-10...30 ( <i>0</i> )	SC object total magnitude
SEQ.INS.SOBJ.DIAMETER	0...300 ( <i>0</i> )	SC object diameter (mas). Only required for <b>calibrator</b> OBs.
SEQ.INS.SOBJ.VIS	0...1 ( <i>1.0</i> )	SC object visibility
SEQ.INS.SOBJ.X	-60000...60000 ( <i>0.0</i> )	RA offset from FT to SC object in mas
SEQ.INS.SOBJ.Y	-60000...60000 ( <i>0.0</i> )	DEC offset from FT to SC object in mas

### 3.1.5 Acquisition keywords

Below follows a more detailed description of the keywords in the acquisition templates:

- `SEQ.FT.MODE`: Set the fringe-tracker mode automatically depending on the magnitude of the fringe-tracking object (for `SEQ.FT.MODE = AUTO`), or manually set the mode (see Sect. 2.2.11).
- `SEQ.MET.MODE`: controls the metrology laser. The dominant noise source in GRAVITY is the back scattering of the metrology laser in the optical fibers in the instrument. The metrology system is not necessary for spectraldifferential observations. To avoid unnecessary noise in those observations at the shortest wavelengths the laser amplifier of the the metrology laser can be turned OFF to reduce the background. Normally the metrology system should be ON, except for the faintest allowed targets where OFF is recommended.
- `SEQ.FT.ROBJ.MAG`: is the total K magnitude of the fringe-tracking object in dual-field and dual-field wide modes. This parameter is required to automatically set the mode of the fringe-tracker.
- `SEQ.FT.ROBJ.HMAG`: is the total H magnitude of the fringe-tracking object in dual-field and dual-field wide modes. This parameter is required for guiding.
- `SEQ.FT.ROBJ.DIAMETER`: This keyword is only required for calibrator observed in dual-field mode. It is used by the pipeline to correct for the calibrator intrinsic size and visibility. It is however suggested to observe calibrators in single-field mode (also if used for dual-field science targets). Therefore this keyword is normally not required.
- `SEQ.FT.ROBJ.VIS`: is the expected visibility of the fringe-tracking object in dual-field and dual-field wide modes. In single-field mode, this parameter is required when automatically setting the mode of the fringe-tracker.
- `SEQ.INS.SOBJ.X/Y`: RA/DEC offsets in milli-arcsecond of the science target relative to fringe-tracking object in dual-field mode. The offsets have to be known to better than 100 mas in order to avoid delays in the fringe search. If this value is calculated from the positions of each component, the distance in RA (in mas) should include the  $\cos(\text{DEC})$  term. The offsets have to be provided for the epoch of the observation. For binaries with high differential proper motion this offset can change significantly within one period.
- `SEQ.FT.ROBJ.ALPHA`: is the fringe tracker object right ascension in the dual-field wide mode. The format is HHMMSS.TTT.
- `SEQ.FT.ROBJ.DELTA`: is the fringe tracker object declination in the dual-field wide mode. The format is DDMSS.TTT.
- `SEQ.FT.ROBJ.PARALLAX`: is the fringe tracker object parallax in arcseconds in the dual-field and dual-field wide modes.
- `SEQ.FT.ROBJ.PMA`: is the fringe tracker object proper motion in right ascension in arcseconds per year. This is only used for the dual-field wide mode.
- `SEQ.FT.ROBJ.PMD`: is the fringe tracker object proper motion in declination in arcseconds per year. This is only used for the dual-field wide mode.
- `SEQ.INS.SOBJ.MAG`: is the total K magnitude of the science target. In single-field mode, this parameter is required to automatically set the mode of the fringe-tracker. In dual-field modes, this parameter is required to set the parameters for the science spectrometer fringe guiding.

- `SEQ.INS.SOBJ.HMAG`: is the H-band magnitude of the science target. This parameter is needed for guiding with the acquisition camera and keeping the science target in the fibre in the dual-field wide mode.
- `SEQ.INS.SOBJ.DIAMETER`: This keyword is only required for a calibrator (if available). It is used by the pipeline to correct for the calibrator intrinsic size and visibility.
- `SEQ.INS.SOBJ.VIS`: is the expected visibility of the science target. It is required in single-field mode when automatically setting the mode of the fringe-tracker and in dual-field modes to set the parameters for the science spectrometer fringe guiding.
- `SEQ.DITHER.X/Y`: RA/DEC offsets in milli-arcsecond of the new FT object relative to the previous FT object in the dither template. The allowed offsets are 8" in any direction; or ~ 20" perpendicular to the roof edge of the beam splitter (reflective part of the roof-prism).
- `INS.SPEC.RES`: This keyword sets the desired SC spectral configuration. It can be:
  - `LOW`: The medium resolution grism is used ( $\mathcal{R} \sim 22$ ). (not offered for dual-field wide)
  - `MED`: The medium resolution grism is used ( $\mathcal{R} \sim 500$ ).
  - `HIGH`: The high resolution grism is used ( $\mathcal{R} \sim 4000$ ).
- `INS.FT.POL` and `INS.SPEC.POL`: These keywords set the desired FT and SC polarisation configuration. It can be:
  - `IN`: Wollaston prism is moved in. The s and p polarisation are split on the detector. This mode offers the highest visibility accuracy at the cost of higher read noise since the light is split over twice as many pixels. This mode is suggested for brighter targets.
  - `OUT`: Wollaston prism is moved out. Both polarisations are combined on the detector. This mode is suggested for very faint targets.

**Note:** Currently the polarisation setting for FT and SC have to be the same.

- `ISS.BASELINE`: The requested VLTI array for the interferometric observations: `small`, `medium`, `large` or `astrometric` with the ATs, or UTs with the UTs. Note that the dual-field and dual-field wide modes can only use AT configurations `small` and `astrometric`. See the [VLTI configuration page](#).
- `ISS.VLTITYPE`: The requested type of interferometric observations; several options can be selected from this keyword list, e.g. “`imaging + timeseries`” for recurring imaging of a variable object. For details, see the [VLTI user manual](#).
- `COU.AG.TYPE`: This keyword defines the type of Coudé guiding to be used. The default setting, `COU.AG.TYPE = ADAPT_OPT`, implies that, for the ATs, NAOMI or, for the UTs, MACAO will be used (equivalent to `COU.AG.TYPE = DEFAULT`). For offset Coudé guiding in the infrared (“CIAO off-axis”), `COU.AG.TYPE = IR_AO_OFFFAXIS` has to be set. In this case, an offset Coudé guide star has to be specified, that is `COU.AG.GSSOURCE = SETUPFILE` has to also be specified (see below). Under special circumstances (e.g. for crowded fields) it might be necessary to use NAOMI or MACAO with the technical CCD (TCCD) by setting `COU.AG.TYPE = ADAPT_OPT_TCCD`, respectively, in order to carry out a manual acquisition and to accurately centre the chosen Coudé guide star before closing the respective AO loop. However this is not necessary for most programmes. Therefore, users are advised to leave `COU.AG.TYPE = ADAPT_OPT`, unless they are sure that CIAO off-axis is required (`COU.AG.TYPE = IR_AO_OFFFAXIS`) or the specific setting has been discussed with the instrument scientist and USD before phase 2 submission.



- **COU.AG.GSSOURCE**: This keyword is used to tell the system which source shall be used for Coudé guiding (see Sect. 2.2.2).
  - In **single-field mode** the keyword can have the following values:
    - \* **SCIENCE**: Coudé guiding on the science object. The coordinates are those given by the RA/DEC fields of the target.
    - \* **SETUPFILE**: Coudé guiding on a chosen guide star different from the science object. The coordinates are those given in the **COU.AG.ALPHA/DELTA** fields in the acquisition template. Please note the constraints for NAOMI/MACAO guide star in Sect. 2.2.6 and 2.2.5 and that these constraints are also pertinent if Coudé guiding are attempted on the **SCIENCE** object.
  - In **dual-field mode** it must always be **SETUPFILE**. The coordinates given in **COU.AG.ALPHA/DELTA** can either be the fringe-tracking target coordinates or the coordinates of a different guide star (Sect. 2.2.2).
  - In **dual-field wide mode** there is also option **FT**, which uses the fringe tracking object for Coudé guiding. The coordinates are those given in the acquisition template in "FT object RA" and "FT object DEC".
- **COU.AG.ALPHA/DELTA**: Coordinates of the Coudé guide star. These keywords should only be specified if the keyword **COU.AG.GSSOURCE** is set to **SETUPFILE**. Otherwise they should be 0 as the Coudé Guiding will use the science target to guide on.
- **COU.GS.MAG**: Coudé guide star V-band (MACAO), R-Band (NAOMI) or K-band (CIAO) magnitude. For MACAO and NAOMI also G band magnitude can be used. This magnitude should **always** be given. In the case of a variable star the faintest magnitude should be given.
- **COU.AG.PMA/PMD**: RA/DEC proper motion of the Coudé guide star in arcsec/year. These keywords should only be specified if the keyword **COU.AG.GSSOURCE** is set to **SETUPFILE**. Otherwise they should be 0.0 as the Coudé Guiding will use the science target to guide on.
- **TEL.TARG.PARALLAX**: This keyword specifies the parallax of the target given in the target tab in p2. For dual-field mode this is the fringe tracker target and for the dual-field wide the science target. It is required for accurate fringe positioning if the parallax exceeds 100 mas.

## 3.2 Observing templates

### 3.2.1 GRAVITY\_dual\_obs\_exp.tsf

Parameter	Range ( <i>Default</i> )	Label
DET2.DIT	0.3 1 3 10 30 100 300 ( <i>0.3</i> )	SC frame integration time (DIT in s)
DET2.NDIT.OBJECT	4 .. 320 ( <i>32</i> )	Number of science target frames (NDIT)
DET2.NDIT.SKY	4 .. 320 ( <i>32</i> )	Number of sky frames (NDIT)
SEQ.RELOFF.X	-2000..2000 ( <i>0.0</i> )	Sequence of SC relative RA offsets (mas)
SEQ.RELOFF.Y	-2000..2000 ( <i>0.0</i> )	Sequence of SC relative DEC offsets (mas)
SEQ.HWPOFF	-180..180 ( <i>0.0</i> )	Sequence of HWP offsets (deg)
SEQ.SKY.X	-8000... 8000 ( <i>2000</i> )	Sky offset in RA (mas).
SEQ.SKY.Y	-8000... 8000 ( <i>2000</i> )	Sky offset in DEC (mas).
SEQ.OBSSEQ	O S ( <i>O S</i> )	Observing sequence of science (O) and sky (S) exposures.

### 3.2.2 GRAVITY\_dual\_obs\_calibrator.tsf and GRAVITY\_single\_obs\_\*.tsf

All remaining observing templates, *GRAVITY\_dual\_obs\_calibrator.tsf*, *GRAVITY\_single\_obs\_exp.tsf* and *GRAVITY\_single\_obs\_calibrator.tsf*, use the same set of keywords.

Parameter	Range ( <i>Default</i> )	Label
DET2.DIT	0.3 1 3 10 30 100 300( <i>0.3</i> )	SC frame integration time (DIT in s)
DET2.NDIT.OBJECT	4 .. 320 ( <i>32</i> )	Number of science target frames (NDIT)
DET2.NDIT.SKY	4 .. 320 ( <i>32</i> )	Number of sky frames (NDIT)
SEQ.HWPOFF	-180..180 ( <i>0.0</i> )	Sequence of HWP offsets (deg)
SEQ.SKY.X	-8000...8000 ( <i>2000</i> )	Sky offset in RA (mas).
SEQ.SKY.Y	-8000...8000 ( <i>2000</i> )	Sky offset in DEC (mas).
SEQ.OBSSEQ	O S ( <i>O S</i> )	Observing sequence of science (O) and sky (S) exposures.

### 3.2.3 Observing keywords

A detailed explanation of the keywords in the observing template follows:

- DET2.DIT: SC frame integration time in seconds.
- DET2.NDIT.OBJECT/SKY: Number of science/sky frames per exposure. The total exposure time (DIT x NDIT) should not exceed 320s. For the best accuracy it is suggested to use a similar number of frames for science and sky and the number of frames should be a multiple of 4 or better 16, the minimum NDIT is 4 (see Sect. 2.3.1).
- SEQ.RELOFF.X/Y: Relative offset of the science fiber, while keeping the fringe-tracking object fixed. The science fiber can be moved by  $\pm 1.0''$  in right ascension and declination. This allows observing several closely spaced science objects or mapping the field to search for faint companions etc. If a fiber offset is desired then the keywords SEQ.RELOFF.X and SEQ.RELOFF.Y need to be filled in the same sequence as in SEQ.OBSSEQ. In addition, the number of entries in all these keywords should be the same. For example for a sequence of SEQ.OBSSEQ = O S O O S, SEQ.RELOFF.X = 0 0 -240 300 0 and SEQ.RELOFF.Y = 0 0 140 -200 0 are valid offset sequences. The offsets are relative, i.e. the applied offset is the cumulative offset of all previous exposure offsets. That is in the example given here, the offset in the fourth exposure would be (+60, -60) with respect to the initial position. At the end of the template the fibres go back to the acquisition position. This mean that a new template will start again from the acquisition position.
- SEQ.HWPOFF: Sequence of rotation offsets for the half wave plate (HWP). This allows observing a source with different half wave plate settings which can be used to infer the polarisation of the object. The keyword needs to be filled in the same sequence as in SEQ.OBSSEQ. Note that polarisation measurements are not officially supported and therefore the use of this keyword requires a waiver approval.
- SEQ.SKY.X/Y: Internal actuator sky offset in RA/DEC (mas), these offsets are used for taking the sky exposure. These offsets will move the actuator in the given directions.
- SEQ.OBSSEQ: Observing sequence of science (O) and sky (S) exposures. Any sequence is possible as long as the total execution time does not exceed the limits discussed in section 2.3.2. As a tradeoff between efficiency and accuracy it is suggested to use a sequence like O S O.

### 3.2.4 GRAVITY\_dual\_obs\_swap.tsf

The swapping template is a stand-alone template and only has one parameter, which can be changed by the user, the fringe-tracker mode.

Parameter	Range ( <i>Default</i> )	Label
SEQ.FT.MODE	AUTO 1 2 7 9 ( <i>AUTO</i> )	Fringe Tracker mode

As for the acquisition templates, the fringe-tracker mode is chosen automatically depending on the magnitude of the fringe-tracking object (for SEQ.FT.MODE = AUTO), or manually by selecting a specific mode (see Sect. [2.2.11](#)).

–oOo–