ESO Phase3 Data Release Description

Data Collection	GRAVITY
Data Provider	ESO, Science Data Quality Group
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Abstract

This is the release of uncalibrated dispersed visibilities (SCIENCE and CALIBRATOR targets) for the GRAVITY instrument. The release of the calibrated dispersed visibilities of the science targets will be available during 2026.
GRAVITY is part of the second generation VLTI instruments. It operates with 4 telescopes. More on the GRAVITY instrument can be found in the ESO instrument pages [1].
The instrument modes included in this release are the GRAVITY modes offered at the beginning of the operations. They are listed in Table 1.
This release is an open stream. It contains data from start of operations in October 2016 and will grow regularly to include the more recent data.
In this first phase only uncalibrated visibilities (CALIBRATOR and SCIENCE targets) will be available. In a second phase, we will also release the science calibrated visibilities.
After these 2 phases have been completed (which is expected to take several months), the aim is to update the stream regularly with the newly acquired data.
Data from this release is processed with pipeline version 1.9 or higher. For the uncalibrated visibilities, detector and instrumental effects have been removed.
The products (uncalibrated visibilities) are OIFITS2 and ESO phase 3 compliant. The OIFITS2 format can be found in A&A. [2]
The quality of the data (which will be described in the section "Data Quality") has been carefully studied with the help of the VLTI expertise centres (under OPTICON-RadioNet-Pilot, EC Contract 101004719).

Overview of Observations

The observations covered by this release have been taken with the GRAVITY modes available for the scientific community at the start of operations (Table 1).
We do not consider observations made using GRAVITY-WIDE (separation of the Fringe tracking and science targets from 2": Unit Telescopes UT, 4": Auxiliary Telescopes Ats and up to 30") or GRAVITY+ which is the upgrade of the GRAVITY instrument and allows increased sensitivity, larger sky coverage and is more focused on scientific science goals.
Data processed for high precision astrometric observations are also included if taken in the modes described in Table 1, but the special analysis to recover the complete astrometry information is not included.
We do not make any difference for data taken with the 8.2m Unit Telescopes (UT), or with the 1.8-m Auxiliary Telescopes (ATs). The only requirement is that the observation is performed with at least 3 telescopes (see section "Data Quality").

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[1] GRAVITY instrument: https://www.eso.org/sci/facilities/paranal/instruments/gravity.html
[2] OIFITS2: https://www.aanda.org/articles/aa/pdf/2017/01/aa26405-15.pdf

Field & Axis	Polarisation	Spectral Resolution
Single-field on-axis	Combined, split	Low ~22, Medium ~500, High ~4000
Dual-field on-axis	Combined, split	Low ~22, Medium ~500, High ~4000
Dual-field off-axis	Combined, split	Low ~22, Medium ~500, High ~4000

Table 1: GRAVITY modes included in this release.

Release Content

GRAVITY is a stream release providing the archive user in the first phase with uncalibrated visibilities (SCIENCE and CALIBRATOR objects) for the GRAVITY modes described in Table 1. The data stream starts with data taken from the start of operations (October 2016) and is growing regularly.
All products are processed using master calibrations (see Table 2.) reduced with the pipeline version 1.7 or higher. The uncalibrated visibilities available to the community have been processed with version 1.9.
The following files are available:

- OIFITS2 [2] and Phase3 [4] compliant uncalibrated visibilities for both night-time calibrators and science data. The FITS files include the data for the Fringe Tracker (FT), the science detector (SC) and the acquisition camera (ACQ).
- Display plots to assess the quality of the data.

The data reduction has been done at the Observing Block (OB) level (see section known issues)
For the uncalibrated visibilities (SCIENCE and CALIBRATOR targets), all the input files belonging to the same template result in one unique product, the quality assessment is done on the result of the first input file.
For the uncalibrated visibilities on calibrator objects, all available data have been processed, including data taken on the observatory dedicated calibrators. For the data products on science objects, data belonging to observing programs 60.A* or 060.A* (header keyword OBS.PROG.ID) have been omitted as they are mostly observed for technical purposes.

Release Notes

Pipeline Description

A detailed description of the GRAVITY pipeline can be found in the pipeline user manual which is available on the ESO pipeline webpages [3].
The pipeline version can be found in the products in the keyword “PROCSOFT”.

Data Reduction and Calibration

The calibration cascade to obtain the two different types of phase3 products is shown in Fig1.

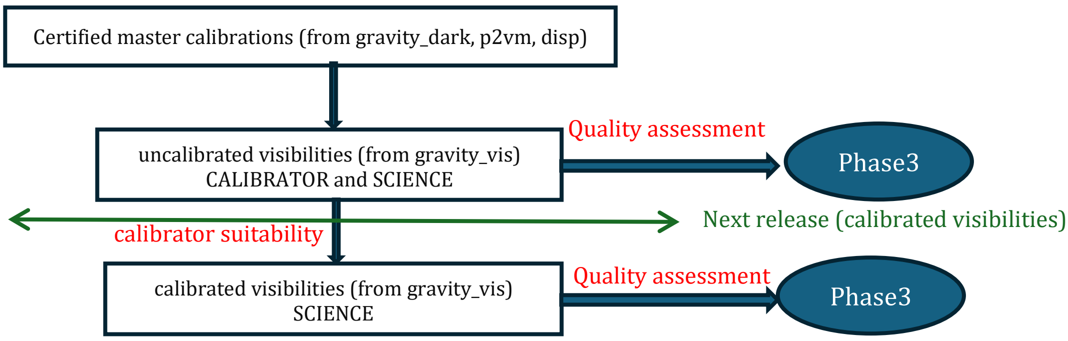

Fig. 1: Calibration cascade

[3] ESO pipelines: https://www.eso.org/sci/software/pipe_aem_main.html

- The raw data is corrected to remove the detector features and the instrumental effects. A summary of the different calibration steps is given in Table 2.

HIERARCH ESO PRO CATG	**recipe**	**Measurement**
DARK	gravity_dark	Dark for the 3 detectors
BAD	gravity_p2vm	Bad pixel map for the 3 detectors
FLAT	gravity_p2vm	Flat for the 3 detectors
WAVE	gravity_p2vm	Spectral dispersion of the beam combiner
P2VM	gravity_p2vm	Instrumental Transmission, coherence and phase

Table 2: Calibrations used to obtain uncalibrated visibilities

Data products format

The data format is given both for uncalibrated (this release) and calibrated Visibilities. They follow the FITS standard for Optical Interferometry (OIFITS2 [2]) and the ESO science data product standard [4].
The instrument setup is coded in the keywords HIERARCH ESO PRO CATG and INSMODE (see Table 3)
The value of the keyword INSMODE is a combination of

- field: SINGLE or DUAL
- spectral dispersion: LOW, MEDIUM or HIGH
- polarisation: SPLIT or COMBINED

The value of the keyword PRO.CATG is a combination of

- the field: SINGLE or DUAL
- the category of the observation: CAL (calibrator object) or SCI (science target)
- the level of calibration: VIS (uncalibrated visibility) or VIS_CALIBRATED (calibrated visibility)

	PRO.CATG	INSMODE	observation
Uncalibrated	SINGLE_CAL_VIS	SINGLE,LOW/MEDIUM/HIGH,SPLIT/COMBINED	Calibrator in single field mode
Uncalibrated	SINGLE_SCI_VIS	SINGLE,LOW/MEDIUM/HIGH,SPLIT/COMBINED	Science target in single field mode
Uncalibrated	DUAL_CAL_VIS	DUAL,LOW/MEDIUM/HIGH,SPLIT/COMBINED	Calibrator in dual field mode
Uncalibrated	DUAL_SCI_VIS	DUAL,LOW/MEDIUM/HIGH,SPLIT/COMBINED	Science target in dual field mode
Calibrated	SINGLE_SCI_VIS_CALIBRATED	SINGLE,LOW/MEDIUM/HIGH,SPLIT/COMBINED	Science target in single field mode
Calibrated	DUAL_SCI_VIS_CALIBRATED	DUAL,LOW/MEDIUM/HIGH,SPLIT/COMBINED	Science target in dual field mode

Table 3: PRO.CATG for the uncalibrated (this release) and calibrated visibilities for the different modes.

For each mode, the product is OIFITS2 [2] compliant and contains the mandatory extensions as well as an additional one: OI_FLUX.
The extensions OI_VIS, OI_VIS2, OI_T3, OI_FLUX are given both for the fringe tracker and the science detector. To differentiate these, the user needs to check the header of the extension and identify the INSNAME which could be GRAVITY_FT (fringe tracker) or GRAVITY _SC (science detector) for a COMBINED observation (Fig. 2).
Each extension contains the data for the different input files.
In the example (fig. 2), the OB contained 5 raw input files resulting in 30 (6 baselines x 5 input raw files) rows in OI_VIS, OI_VIS2 and 20 (4x5) in OI_T3 and OI_FLUX.

[4] ESO science data product standard: https://www.eso.org/sci/observing/phase3/p3sdpstd.pdf

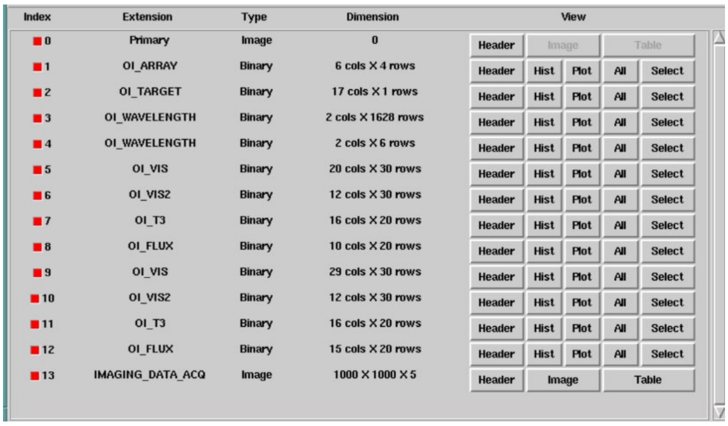

Fig. 2: Different extensions in the product, this is an example of a COMBINED observation.

In the case of SPLIT (so 2 polarisations), there will be 4 tables with each name (OI_VIS, OI_VIS2, OI_T3 and OI_FLUX). Like for the COMBINED mode, the extensions are differentiated with the INSNAME keyword: GRAVITY_SC_P1 and GRAVITY_SC_P2 for the 2 polarisations of the science detector and GRAVITY_FT_P1 and GRAVITY_FT_P2 for the 2 polarisations of the FT (Fig. 3).

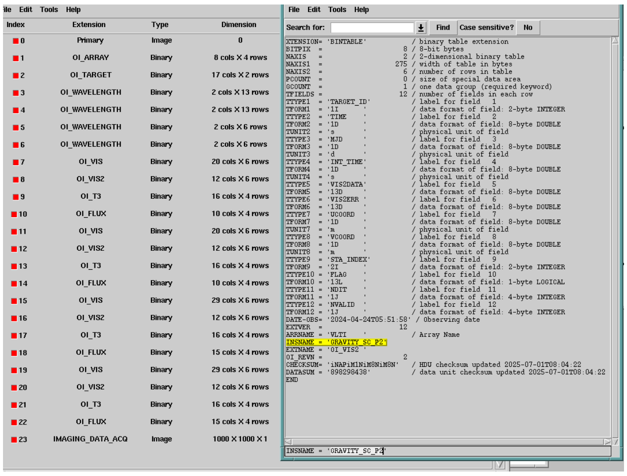

Fig. 3: Different extensions in the product, this is an example of a SPLIT observation.

Data Quality

Master Calibrations:

The master calibrations (Table 2.) since start of operations have been processed (or reprocessed if needed) with a pipeline version 1.7 or higher. They have been quality-reviewed and certified and are available in the ESO archive when requesting science data.

Quality assessment of the uncalibrated visibilities:

The GRAVITY pipeline produces for each product a large number of quality control parameters which record the state of the system, the atmospheric condition and the quality of the data.
To be able to assess in a semi-automatic way the quality of the data, we needed to identify a small set of quality control parameters.
An extended study of a large number of products in the different modes has been conducted between ESO and the VLTI expertise centre community [5] (led by the Portuguese VLTI expertise centre). For the different instrument modes, a thorough analysis of all the control parameters and the different correlations between them have been performed mostly by the expertise centers. From this analysis, it was found e.g. that no clear correlation was seen between the ambient conditions and the image quality of the acquisition camera. When a correlation existed, we carefully looked at a large number of files to further select a reasonable number of quality parameters to assess the data quality.

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[5] https://european-interferometry.eu/vlti-expertise-centers/

The further complication was to make sure that the defined quality parameters were valid for all the instrument modes.
After identifying the set of quality control parameters to look at, we needed to define ranges. We decided to implement 3 different thresholds for bad quality, warning and good quality (Table 4). The number of "bad" and "warning" flags is given in the product header as:
"HIERARCH QC NFLAG BAD": total number of above QC parameters of bad quality,
"HIERARCH QC NFLAG WARN": total number of above QC parameters of "warning" quality,
"HIERARCH QC TOT NFLAG BAD": total number of above QC parameters of bad quality (excluding the SC SNRB AVG)
Additional information about the QC parameters listed in Table 4 can be found in the GRAVITY pipeline manual [6].
Each of the following keywords is given for each of the 6 baselines, which gives at the end a total of 36 values to assess the quality.
If a QC parameter (with the exception of SC.SNRB.AVG) has the 6 values in the "bad" category, the product should be considered as of inadequate quality. In the case of a calibrator object, these are not ingested. In the case of a SCIENCE observation, the product is made available, but should be used with caution.
If a user is looking for very high quality or accuracy data, the QC.NFLAG.WARN value should also be taken into account for further analysis.
When one telescope is not operating, we decided to keep the product, the 3 baselines remaining could be of good quality.
If a specific observation has no phase3 product, this means that either the pipeline fails or the data were rejected because of insufficient quality. The raw data is still available in the archive for tailored processing.

Header keyword starts with HIERARCH ESO QC	Description (see[6])	Bad quality	Warning flag	Good quality
FT TRACKING RATIO (in %)	Fringe tracker tracking ratio	< 80	[80,90]	>90
FT PHASE RMS	Fringe tracker root mean square of the phase	>0.7	[0.5,0.7]	<0.5
VFACTOR	Ratio of frames non affected from the visibility loss due to flux flickering	<0.45 and >1.1	[0.45,0.8]	>0.8
PFACTOR	Ratio of frames not affected by the visibility loss due to phase jittering	<0.6 and >1.1	[0.6,0.85]	>0.85
FT SNRB AVG	SNR for the fringe tracker channel	<10	[10,30]	>30
SC SNRB AVG	SNR for the science channel	<50	[50,150]	>150

Table 4: QC parameters to assess the quality of the data. If any of the above QC parameters of a calibrator product has the 6 flags "bad" (excluding the SC SNRB AVG), the product is not ingested in the phase 3 archive. If the product comes from a SCIENCE target, it is checked before ingestion.

Quality assessment for ingestion of the uncalibrated visibilities of the calibrators:
To decide if the uncalibrated Visibility of a calibrator should be ingested, we looked at the QC parameters mentioned in Table 4. If none of the first 5 QC parameters (excluding SC SNRB AVG) had the 6 values corresponding to one parameter flagged as bad, the data have been ingested.

[6] Pipeline: https://ftp.eso.org/pub/dfs/pipelines/instruments/gravity/gravity-pipeline-manual-1.9.6.pdf

If the 6 values for the SC SNRB AVG were flagged as bad, the result has been checked before ingestion.

The ingestion of the uncalibrated visibility product for a calibrator is solely based on the quality of the data, not on suitability of the object to be used further to calibrate the science visibility.

The suitability of the object to be used further to calibrate the science visibility is important for the next release of calibrated visibilities.
In some instances, we found that the data set, even flagged as calibrator by the observer could not be used to further calibrate the science. The latest version (2025) of the JSDC catalogue [8] and the columns CalFlag and BADCAL (see [7]) will be used to identify "non suitable" calibrators. The most common "non-suitable" calibrator observed is a multiple object (see Fig. 7).
If the object has a diameter listed in the JSDC catalogue [8], "HIERARCH ESO QC TF CAL_SC DIAM SOURCE" = 'CAT' can be found in the header. The pipeline matches the RA and DEC coordinates for identification and extract from the catalog the name of the object (HIERARCH ESO QC TF CAL_SC DIAM CATNAME), the diameter (HIERARCH ESO QC TF CAL_SC DIAM) and its associated error (HIERARCH ESO QC TF CAL_SC DIAM ERR). The same is done for the Fringe Tracking object.
If the above keyword has a value 'HDR', this means that the calibrator has not been found in the JSDC catalog. If the astronomer who requested this observation indicated the diameter it be present in the header (HIERARCH ESO INS SOBJ DIAMETER and HIERARCH ESO FT ROBJ DIAMETER). These values have to be taken with caution.

Quality assessment for ingestion of the uncalibrated visibilities of the science objects:
We also checked the quality of the uncalibrated visibilities of the science objects based on the 6 QC parameters described in table 4.
For science objects, we also decided that we could ingest products which did not fully pass our quality assessment. It is for ex. the case of data where fringe tracking was acceptable but some of the QC parameters such as, for ex. PFACTOR or VFACTOR were not optimal.

Preview image and plots:
The preview image (Fig. 4) is a representation of the raw input files.

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[7] Column CalFlag: Calibrator Flag (bit field): bit 0 is set if LDD_CHI2 is above 5 or the spectral type is missing or not precise (BRIGHT); bit 1 is set if the star is a known double in WDS (Cat. B/wds/wds) with separation inferior to 1 arcsec; bit 2 is set if the star is, according to Simbad's OTYPEs, one of the codes which signals a possible binarity or pulsating stars; bit 3 is set if the star has neighbors within 3 arcsec (ASCC / GAIA / 2MASS).
Column BADCAL: JMMC badcal identifier (https://www.jmmc.fr/badcal/)

[8] JSDC calibrator catalog: https://apps.jmmc.fr/~sclcat/JSDC/ and http://cdsarc.u-strasbg.fr/cgi-bin/VizieR?-source=II/346

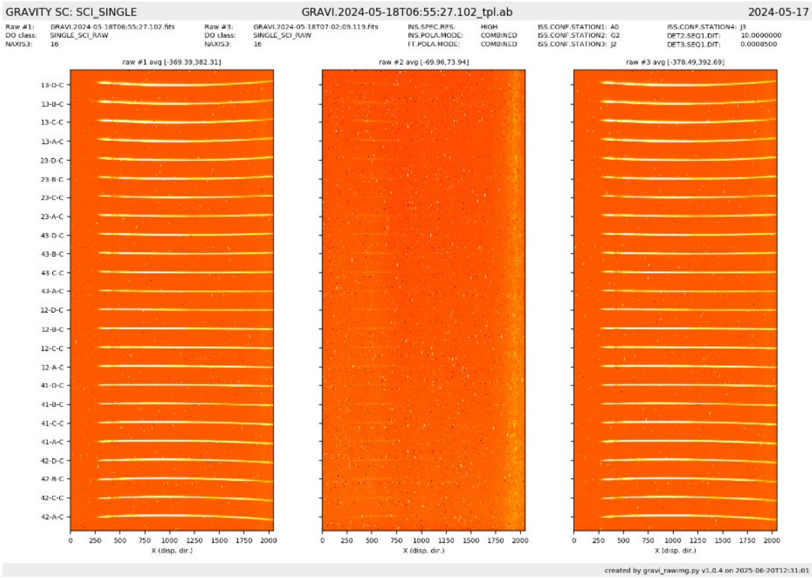

Fig. 4: Preview image of the input raw data. In this example the raw files #1 (left) and #3 (right) are on the object, #2 (middle) is a sky frame.

Preview plots for quality checks:

Figures 5, 6 and 7 show data of different quality.
The different sections of the preview plots are described below (see colored boxes and tags on Fig. 5):

1 (blue) The information on the top shows the value of some of the header keywords such as category of the product, how many files were used as input, pipeline version as well as the characteristics of the Fringe tracking and science target, the instrument setup and the atmospheric conditions. It summarizes the number of QC parameters which have been rejected (HIERARCH ESO QC TOT NFLAG BAD).

2 (red) The table shows the different QC parameters that have been defined to assess the quality of the data. The cell is colored in somewhat darker red if the value is considered bad, and in light red if the value is a warning. In the example shown in Fig. 5, the data set passed the data quality, while for Fig. 6, the data did not pass the quality assessment.

3 (green) The four images (4 telescopes) show part of the acquisition camera where the science target and the fringe tracker object are located. This position is sometimes wrongly calculated by the pipeline (see known issues). In this case the object will be outside the circle.

4 (purple) The plots show:

4a. VIS2DATA: the squared visibilities for the 6 baselines, both for the fringe tracker and the science target. The visibilities are expected to be between 0 and 1.

4b. VISPHI The phases for the 6 baselines (in deg).

For these 2 plots, the Fringe tracking data measurements are represented as squares.

4c left FT FLUXDATA: the fringe tracker flux for the 4 telescopes,

4c right SC FLUXDATA: the object flux for the 4 telescopes

The fluxes on the 4 telescopes are expected to be within the same range.

4d. T3PHI: the closure phases for the baseline triangle (deg). As above, the Fringe Tracking points are shown as squares

4e. The (u,v) coverage which shows the position of the telescopes at the time of the observation.

The Fringe tracker (FT) data are shown as squares, while the observed object is shown as a continuous line.
When the observation is performed in SPLIT mode, the blue represents the polarisation 1, the red the pol 2 (Fig. 5).

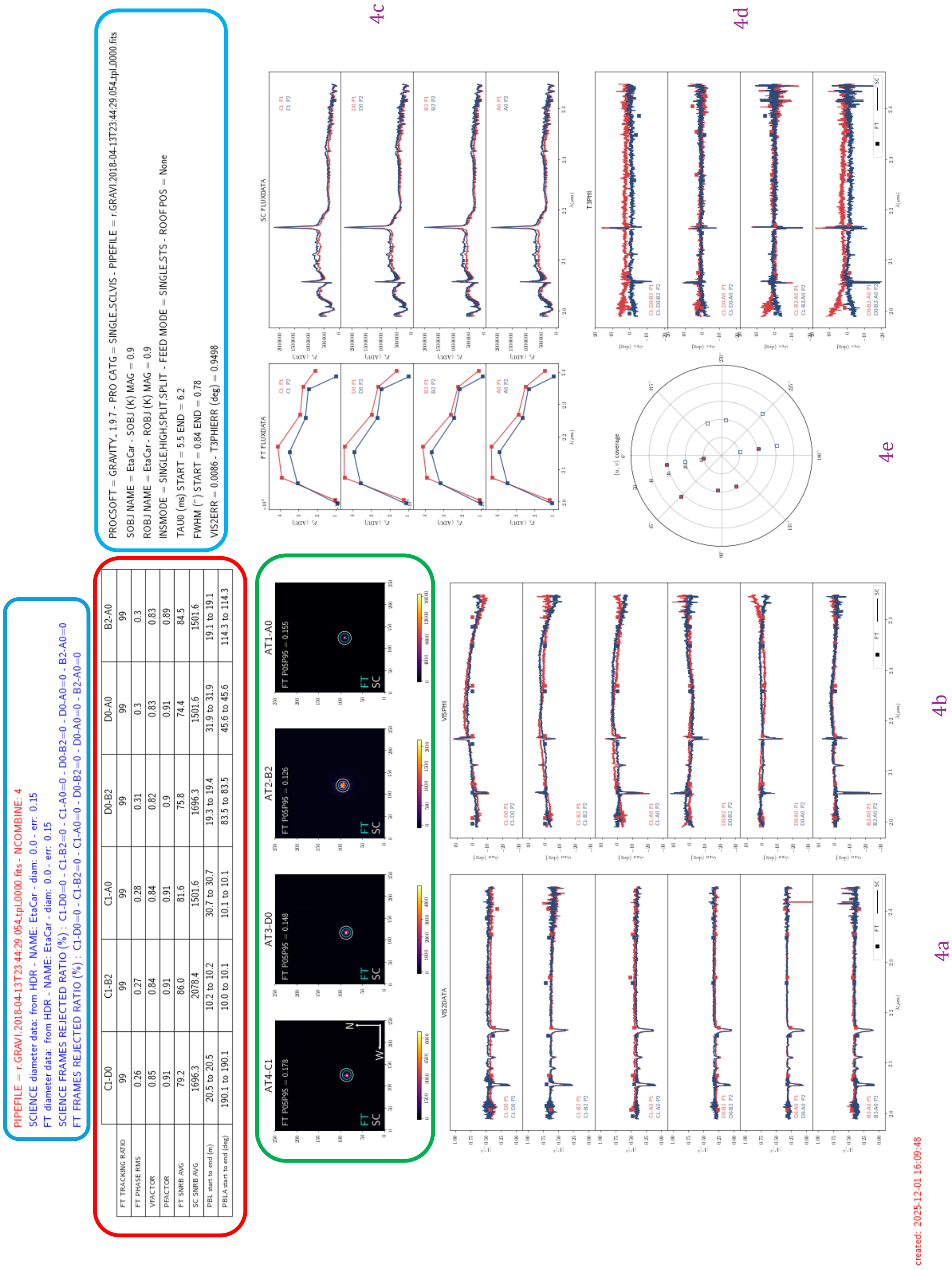

Fig. 5: Preview plot for a data set which passed the quality control. The description of the different plots can be found above. As explained in Table 4, the assessment is done on a set of QC parameters calculated by the pipeline. These parameters are scored. In this ex. none of the parameters have been flagged. This data set is considered good quality. The colors red and blue represent both polarisations.

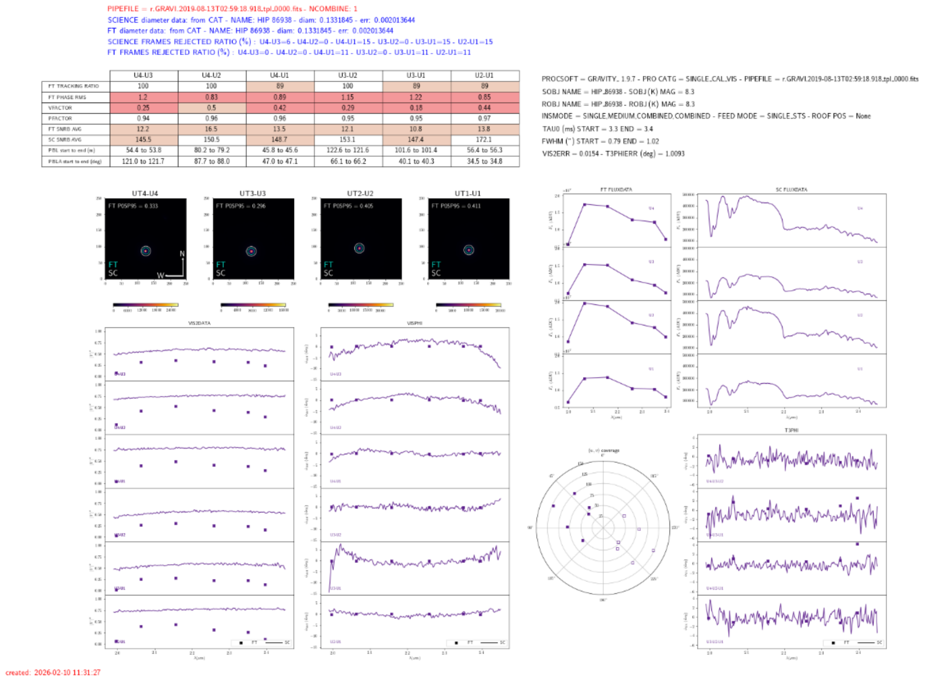

Fig. 6: Preview plot for a data set with 6 "bad" flags for the FT phase rms. The somewhat darker red cells in the table identify the non-optimal "bad" parameters. The lighter pink cells identify the parameters which fall in the "warning" category. This calibrator product is rejected and is not available in the ESO phase3 archive. The raw data is available in the ESO archive for tailored processing.

As mentioned above, some data sets flagged as calibrators are of scientific value but should not be used to further calibrate science data. In the following figure (Fig. 7) this multiple object is considered in the ESO archive as a calibrator (raw file with DPR.CATG=CALIB) but will not be used to further calibrate science data for the next release (calibrated visibilities).

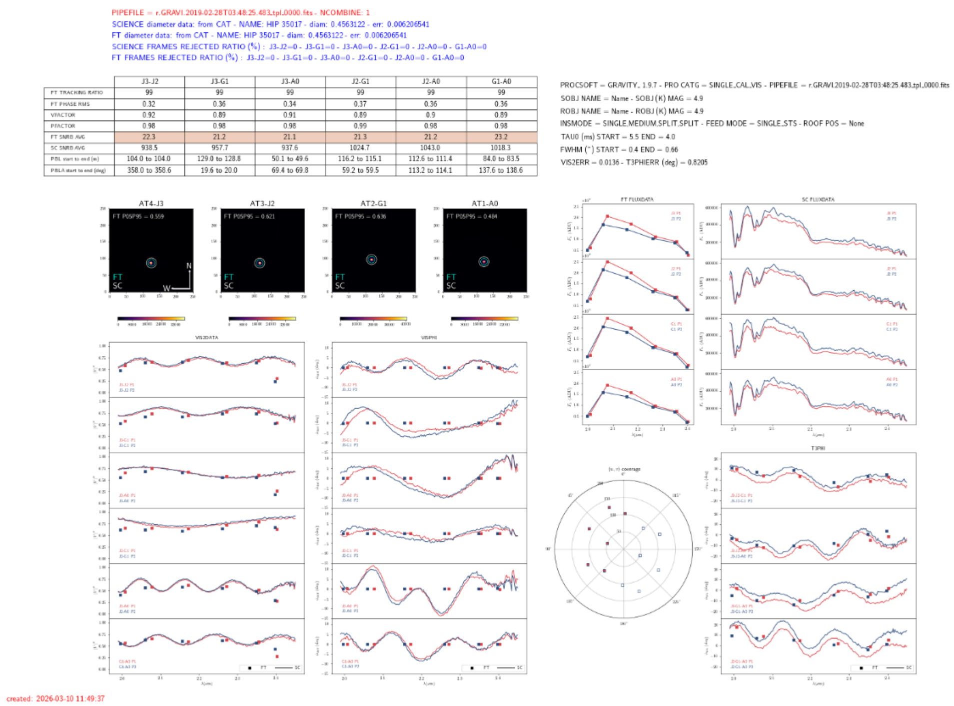

Fig. 7: This object is listed in the BAD Calibrator list (https://www.jmmc.fr/bad-cal/show.jsp?type=all&display=complet) as potential binary (https://www.jmmc.fr/bad-cal/show.jsp?type=detail&id=140). This product will not be used to calibrate a science object.

Known issues

The already known processing problems are described in the pipeline user manual [3].

- The accuracy in the wavelength calibration can generate biases in the closure phase of a maximum of 3deg.
- When there is a low number of valid frames (< 5) the final uncertainties are not reliable. The number of valid frames can be found in the OI_VIS2 extension table (INSNAME = GRAVITY_SC) under the column NVALID.

During the initial work to prepare for this release, some additional issues which do not affect the quality of the final science products have been found. These issues have been found with v 1.9.3 and 1.9.7, it should be corrected in later versions.

- The position of the science and Fringe Tracker object is sometimes not picked at the right position by the pipeline. This does not affect the quality of the data but the image in the preview plot could show the object at the wrong position (Fig. 9)

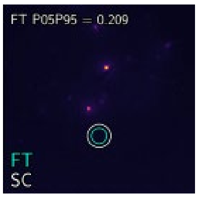

Fig. 9: the position of the science and fringe tracking object has been wrongly picked up

- The QC parameter values reflect the quality of the input raw data and not the quality of the output science data.
  For ex. concerning the VFACTOR: any single frame below VFACTOR=0.1 (default value for the pipeline) is removed from the final integration. It is not, however, removed from the calculated QC parameter shown in the header of the final product: HIERARCH QC VFACTORij_Pk (ij: baseline, k Polarisation).
  The consequence in some cases is that the VFACTOR value could be outside of the good quality thresholds but the final data product quality will be acceptable, this is the case when in the input raw data some frames are good and a few frames are terrible, the VFACTOR will reflect these input data (including the bad frames) while the final QC and the final data quality could be fine.
  A user could judge the reliability of the values of the VFACTOR and PFACTOR QC parameters by checking the header keywords "HIERARCH ESO QC REJECTED RATIO SCij" which represent the frame rejection ratio of the science frames. The value of these header keywords is also shown on the quick look plots of the uncalibrated Visibilities.
- Because the processing is done per OB, the quick look plot only shows the results of the first input file. The QC parameters are averaged over the full data set.
- In DUAL mode, when an Observing Block (OB) contains several raw files on object, the observer can define different positions for each "object" raw file. This means that in the same OB, the different files could be on different targets. Up to end of 2025, this was not commonly used, and these products have not been ingested. DUAL Field data observed from January 2026 will be processed file by file and not OB by OB.

File identification

Both uncalibrated and in a later release calibrated visibilities products contain the mandatory extension tables for the OIFITS2 [2] as well as OI_FLUX which is an additional table.
The different products can be classified using the header keyword PRO.CATG which is listed below in Table 5 and Table 6.

To distinguish between uncalibrated (this release) and calibrated visibilities (future release), an additional header keyword VISCAL is also written in the product, which value can be either UNCALIBRATED or CALIBRATED.
The file naming convention (ORIGFILE) is:
GR_<type>_OBS.ID_ARCFILE_<array>_<field_mode>_<resolution>_<polarisation_mode> where:

- GR: GRAVITY instrument
- <type> is described in Table 5 and Table 6
- OBS.ID: keyword header
- ARCFILE: truncated name of the first input raw file
- <array> could be A1234 if the observation was done on the Auxiliary Telescopes (AT) and U1234 if the data were acquired with the Unit Telescopes (UT)
- <field_mode>: SINGLE or DUAL
- <resolution>: LO (Low), ME (Medium), HI (High)
- <polarisation_mode>: COM (COMBINED), SPL (SPLIT)

Type	Product category (PRO.CATG)	Format	Description	VISCAL header keyword
SCVS	SINGLE _CAL_VIS	OIFITS2	CALIBRATOR, single mode	UNCALIBRATED
SSVS	SINGLE _SCI_VIS	OIFITS2	SCIENCE, single mode	UNCALIBRATED
SCVD	DUAL_CAL_VIS	OIFITS2	CALIBRATOR, dual mode	UNCALIBRATED
SSVD	DUAL_SCI_VIS	OIFITS2	SCIENCE, dual mode	UNCALIBRATED

Table 5: For the uncalibrated visibilities files, no ancillary FITS files are provided.

Acknowledgements

VLTI expertise centers (https://european-interferometry.eu/vlti-expertise-centers/) have been contributing in setting up the automatic quality control of the products released to the community. They also defined the content of the plots which allow a user to check quickly if the data fulfills what is expected for the science goal.
This study was done under an Opticon RadioNet Pilot contract (EC contract 101004719 26-UPORTO: GRAVITY curated data).

According to the Data Access Policy for ESO data held in the ESO Science Archive Facility, all users are required to acknowledge the source of the data with appropriate citation in their publications.

Since processed data downloaded from the ESO Archive are assigned Digital Object Identifiers (DOIs), the following statement must be included in all publications making use of them:

- *Based on data obtained from the ESO Science Archive Facility with DOI: https://doi.org/10.18727/archive/101*