THE MIDI DATA FLOW: FIRST OBSERVING PERIOD

MIDI, THE FIRST SCIENTIFIC INSTRUMENT FOR THE VLTI, HAS BEEN OFFERED TO THE COMMUNITY SINCE THE BEGINNING OF THE OBSERVING PERIOD P73. IN THIS ARTICLE, WE PRESENT A NUMBER OF DIFFERENT SOFTWARE TOOLS THAT ARE AVAILABLE FOR THE PREPARATION OF OBSERVATIONS, THE PROCESSING OF MIDI DATA IN REAL-TIME DURING OBSERVING, THE PIPELINE REDUCTION OF DATA AT THE COMPLETION OF OBSERVATIONS AND THE DISTRIBUTION OF THESE DATA.

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MIDI IS THE MID-INFRARED Instrument for the VLT Interferometer (Leinert et al., 2003). It covers the wavelength range 8 to 12 microns and records spectrally-dispersed fringes, making it possible to reach a resolution (λ/B) of 20 milliarcsec at 10 microns. The main scientific objectives include the study of protostars and very young stars, circumstellar discs, brown dwarfs, tori around galactic nuclei, the centre of our own galaxy and the search for exoplanets. Recent observations of the Seyfert core of NGC1068 in the near-infrared (using the VINCI instrument; Wittkowski et al., 2004), as well as in the mid-infrared (MIDI; Jaffe et al., 2004) illustrate the possibilities offered by infrared long-baseline interferometry (Richichi & Paresce, 2003).

The Service Mode (SM) has been supported at the VLT since the beginning of operations with the first telescope ANTU in 1999 (Comeron et al., 2003). With MIDI, an interferometer is offered to the whole community for the first time. Here we present a suite of observation preparation, data processing and quality control tools that has been developed for MIDI observations. Drawing on the experience gained with the VLTI Commissioning instrument, VINCI, we show the first results of the quality control of interferometry observation data.

OBSERVATION PREPARATION

The science operations of the MIDI instrument from the proposal stage to data delivery are integrated into the general VLT scheme. For the current observing period, P73, a total of 20 MIDI programmes has been accepted and scheduled for observation. From these, 12 are "Service Mode" programmes and 8 are "Visitor Mode" programmes. A total of 71 hours of VLTI execution time has been scheduled for Service Mode. These P73 programmes cover the scientific categories "B: Galaxies and Galactic Nuclei", "C: Interstellar medium, star and planet formation" and "D: Stellar evolution" (see www.eso.org/observing).

WEB TOOLS FOR VLTI OBSERVATION PREPARATION

In order to plan an interferometric observation and to assess its feasibility, one needs adequate tools to model the visibility for a specified array configuration, taking into account constraints like shadowing effects or the range of the delay lines. In addition, appropriate calibration stars must be selected. Two specific tools are provided for this purpose: the VLTI Visibility Calculator (*VisCalc*) and the calibrator selection tool (*CalVin*). *VisCalc* provides calculations of simulated dispersed visibilities based on software models of the VLTI instruments. The declination and spectral energy distribution, as well as the source geometry, are parameters used to specify the observation target. Visibilities are calculated analytically for uniform discs, gaussian discs and binaries. Visibilities may also be calculated numerically for a user-provided brightness distribution which is uploaded as a FITS file. The user-specified observation conditions include the starting hour angle and the duration of the observation, as well as the instrument and array configuration. Different results can be displayed (Fig. 1) including the *uv*-tracks, the input image and its Fourier transform, plots of visibility versus time, visibility squared versus time, loss of correlated magnitude, or the illumination distribution.

The calibrator selection tool (*CalVin*) provides a similar interface and involves a two stage selection process. On the first input page, the target coordinates, the array and instrument configurations can be selected. The default search criteria are displayed on an intermediate page which allows the search parameters to be refined. On the results' page, the table of matching calibrators (Fig. 1) is listed. For all matching calibrators, the visibility and "observability" information is calculated and displayed. It is then possible to use *VisCalc* for a more comprehensive calculation of the visibility information.

Both tools can be accessed from the VLT Exposure Time Calculators page on http://www.eso.org/observing/etc. The standard version shows only those configurations that

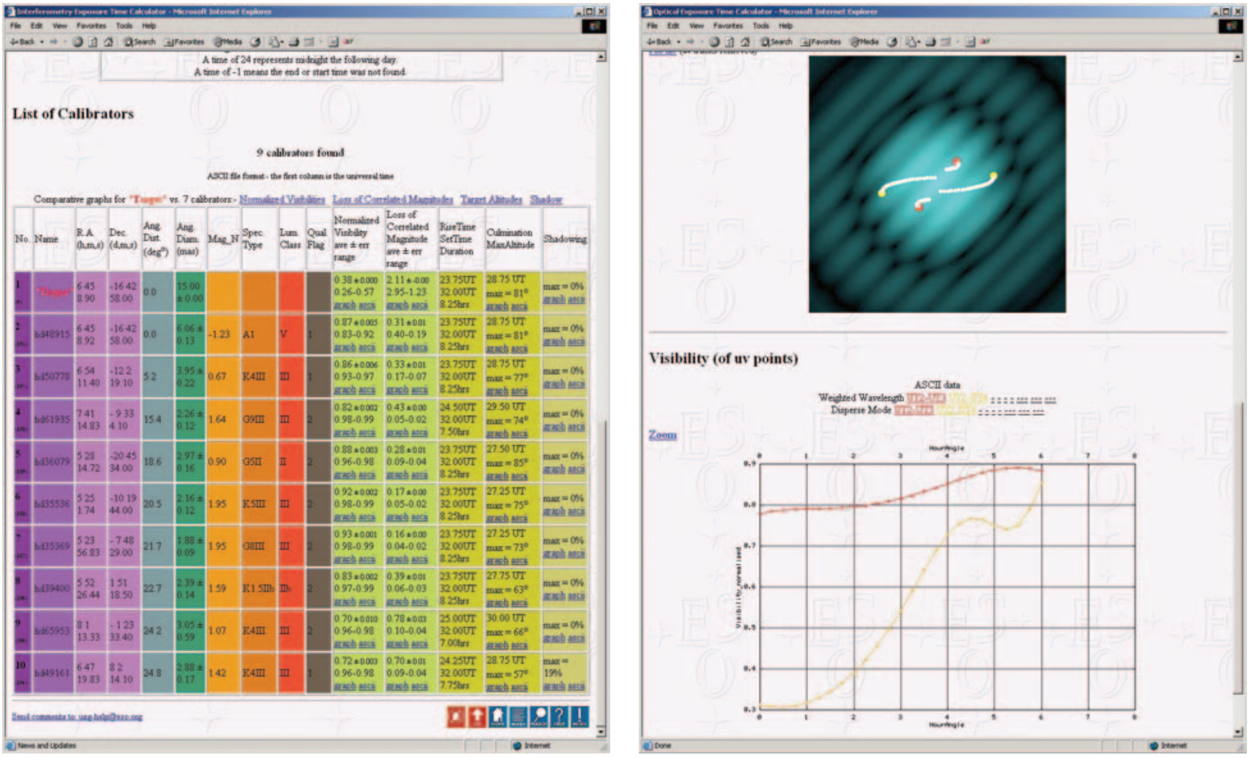

Figure 1: Sample results from the calibrator selection tool *CalVin* (left) and from the visibility calculator *VisCalc* (right).

are offered for the current *Call for Proposals*. It is updated for each new Call for Proposals in order to reflect the offered VLTI baseline configurations and instrument modes. An "expert" version, accessible from the ETC preview page (http://www.eso.org/observing/ etc/preview.html) offers an extended interface with many more choices. It supports the modes and configurations that are currently not offered.

MIDI Calibrators

To obtain a good accuracy for the calibrated visibility measurements, it is important to establish a list of calibration stars that do not show any strong features and that are neither variable nor multiple. In 2003, ESO organised a workshop on VLTI calibrators (Richichi et al., 2003). During this workshop, the following two strategies were discussed:

- The search for suitable objects, in large catalogues like CDS (http://cdsweb.u-strasbg.fr), based on specified criteria.
- Establishing a smaller set of calibration stars based on suitable objects in the literature (Richichi & Percheron, 2002). If necessary, complementary measurements can be taken (Kimeswenger et al., 2004). This strategy reduces the list, but it preserves objects which have already been studied. Furthermore, with a smaller list, the frequency of observations will be greater, and hence detailed knowledge of the sources could be acquired more rapidly.

In the case of MIDI, the calibrators used in *CalVin* are extracted from a list that is provided by the MIDI consortium. Photometry was performed for these stars and the limb-darkened diameter was obtained by fitting atmosphere models. The initial list contains more than 500 calibrators and after careful filtering, based on the "goodness-of-fit" of the atmosphere model, as well as the experience with VINCI observations, we selected nearly 200 potential MIDI calibrators for P73. The following graph (Fig. 2) shows the distribution of the size and accuracy of the MIDI calibrators.

Even though this list is still evolving, we still encourage the use of *CalVin* calibrators. There are at least two advantages to this strategy. Firstly, a large volume of data on *CalVin* calibrators is obtained and therefore their quality can be verified. The goal is to update the *CalVin* list with re-measured objects (see lessons learnt with VINCI). The second advantage is that by using the same calibrators through the year, it becomes possible to study changes in instrument performance over extended timescales.

Phase 2 and OB Preparation

The observation details, including finding charts and observing strategy, are specified by the user in Observation Blocks (OBs) that are assembled with P2PP (Phase 2 Proposal Preparation, www.eso.org/observing/p2pp). MIDI-specific information includes parameters such as the array configuration, a range of Local Sidereal Time (LST), and the specification of a calibration star. Using the LST

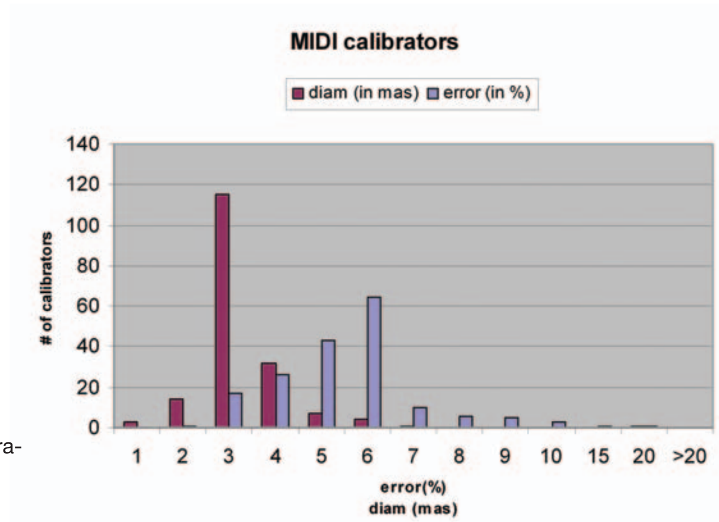

Figure 2: Distribution of the size and associated accuracies for the MIDI calibrators used in *CalVin*.

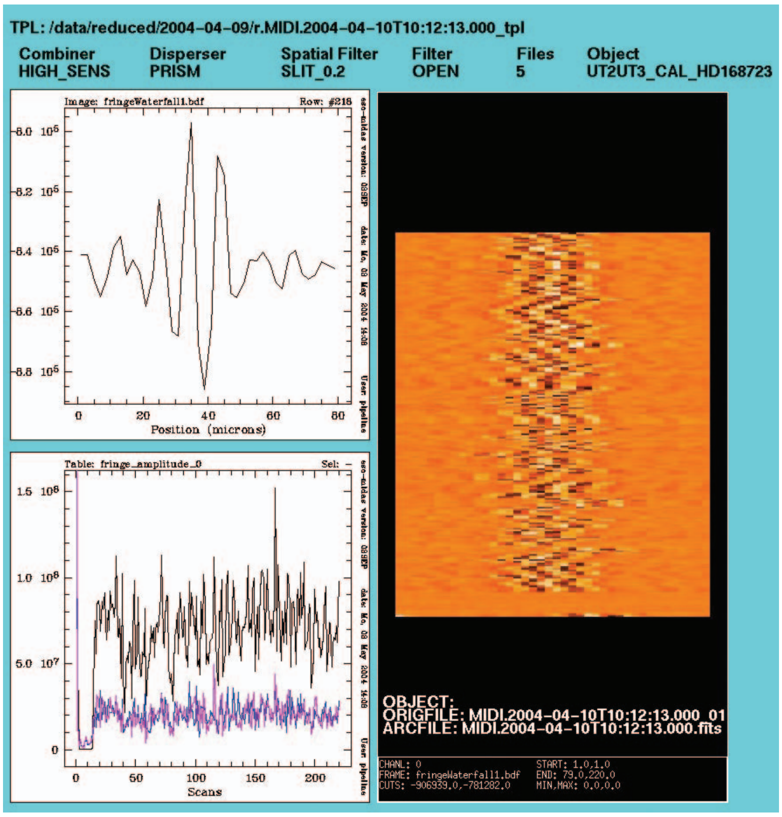

Figure 3: MIDI waterfall display. This example of the output display illustrates three components. The image on the right-hand-side is the so-called 'waterfall display' which shows the fringes in the entire data. The diagram on the top left-hand corner displays the central fringe and the one on the bottom left-hand corner is the result of the fringe amplitudes for the entire scan.

constraint, a user can specify the projected baseline length, the projected azimuth angle or the zenith distance. The calibration star is selected on the basis of criteria such as angular distance, brightness or spectral type (see Sect. MIDI Calibrators).

For the observing period P73, only one observing mode is offered. This is the dispersed-fringe mode, which uses a prism to provide a spectral resolution of R~30 at *N*-band (10 microns). In P73, observations are executed as pairs of science and calibration star OBs with an execution time of 1 hour per calibrated visibility spectrum. As a result, the user only needs to specify a few parameters in P2PP.

MIDI observations are scheduled in discreet units, or blocks. Two major time slots have been reserved for MIDI Service Mode observations, one at the beginning of April and a second one at the end of July. The first block of Service Mode observations using the UT2-UT3 baseline took place at the beginning of April and was very successful. A total of 30 pairs of science and calibration star OBs (30 hours of VLTI observing time, i.e. 60 hours of telescope time) have now been successfully executed. However, the scheduling of interferometric observations with several telescopes and matched LST constraints is complex and, for this reason, carry-overs for MIDI programmes are not offered at this stage.

Data Reduction Pipeline

The algorithms used in the data reduction pipeline have been described and provided by the MIDI consortium and adapted in the Data Flow System environment. The on-line pipeline infrastructure at Paranal provides an environment where the pipeline recipes are executed automatically. This task includes the recognition of the type of raw frames (an input data file with classification information), assignment of the appropriate reduction recipe, selection of the appropriate reference data and the execution of the reduction steps. The pipeline infrastructure receives the raw frames from the on-line archive system. It then classifies the incoming frames in accordance with a set of rules.

The MIDI raw data are delivered to the pipeline in the form of several FITS files. These files contain the results of both interferometry as well as the photometry observations, for calibrators and science targets. Since the interferometry data volume is rather large (about 1GB per visibility point) it is delivered in several split FITS files. The procedure for the data reduction involves two stages. In the first stage, when calibration data arrives, the raw undispersed visibilities are calculated from the dispersed-fringe data (Fig. 3). Additionally, the theoretical visibilities are also computed. This is achieved by extracting the necessary parameters from the calibrator database, based on the same list as used by the web-based calibrator selection tool *CalVin*. From the calibrator raw visibilities and the theoretical visibilities, the transfer functions are computed. In the second stage, when the science data is available, the calibrated visibilities are computed by using the above transfer function as well as the raw undispersed science visibilities. At Paranal, the Instrumental Transfer function can only be derived from observations that immediately precede that of the science object. In Garching, the association process can make use of all the calibration data taken during a certain period of time, including calibrations taken after the science observation. It is possible for instance to use either the closest calibrator in time or any other more suitable calibrators.

With MIDI, one had to face the challenge of large data volume (20 GB per night for MIDI) and therefore all efforts have been made to streamline the processing. The pipeline recipes currently make it possible to process one night of data (about 20 GB) in about half an hour. This enables immediate on-line data quality assessment and provides ample time for the off-line data quality control at Garching.

The off-line processing at Garching yields a number of product files providing the visibility results and all the information for the Quality Control. This allows the QC scientist and the PI to quickly assess the quality of the data. All observations are processed with a set of pre-defined parameters, which are a compromise to allow both consistent quality control and science reductions. In some cases, the resulting science products alone (e.g. uncalibrated visibilities with uncertainties) may be sufficient to achieve the overall science objectives. However, it is usually expected that some data re-processing will be necessary to achieve the optimal result.

Data Quality Control

Quality Control (QC) consists mainly of verifying the quality of the data, producing calibration data, and monitoring the instruments on different time scales.

During operation, several types of calibration data are evaluated for the purpose of quality control: technical calibrations such as the determination of the read out noise, the characterisation of the detector linearity, the stability of the reference pixels, the dispersive elements transmission, the wavelength calibration and the determination of the output of the instrument using a known source, and the calibration of the science target using an astronomical calibrator. The technical calibrations are used for the scientific data reduction as well as for the monitoring of the health of the instrument in order to detect any problems (for example transmission degradation of an optical ele-

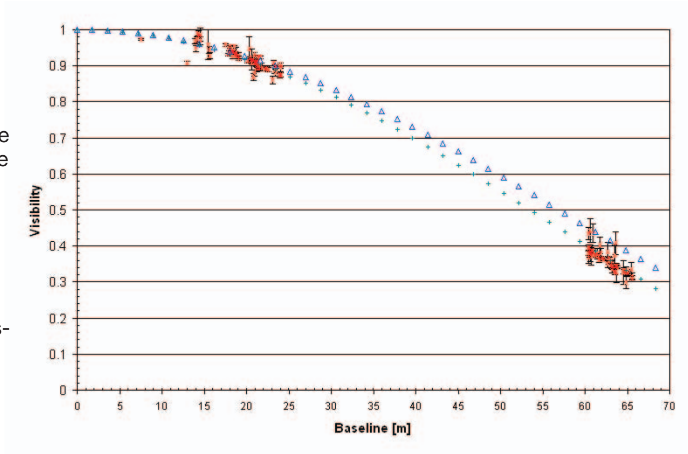

Figure 4: Data obtained on a potential calibrator (α CMa) using the VINCI instrument. The projected baselines range from 7 metres to more than 60 metres. The previously assumed diameter (blue triangles) could be refined using VINCI data (red crosses) and a new diameter (green crosses) could be fitted to the measurements.

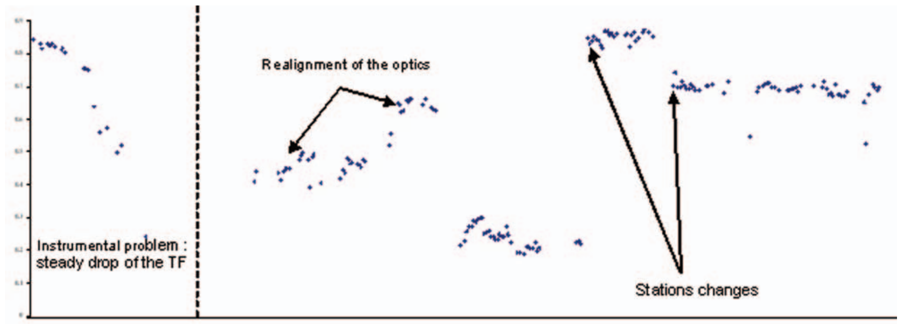

Figure 5: The instrumental transfer function for the commissioning instrument VINCI is shown for selected periods. Each dot represents a night of measurements on selected calibrators. The large jumps illustrate changes in the instrument configuration, while the small variations from one night to the next are due to atmospheric fluctuations.

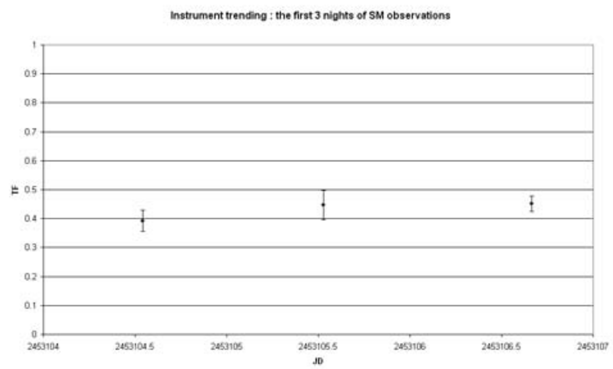

Figure 6: The same bright calibrator was observed each night during the first MIDI Service Mode (SM) run to provide initial trending data. As with VINCI, some of the transfer function (TF) variations are due to atmospheric fluctuations.

ment). More information on Quality Control can be found on www.eso.org/observing/dfo/quality.

Lessons learnt with VINCI

During the 3 years of VINCI operations (since the first fringes in March 2001), we systematically observed potential calibrators. We have been able to monitor these objects and to estimate more accurate diameters (Fig. 4).

We selected the list of potential MIDI calibrators for P73 based on the results from VINCI observations. However, one should recall that since the wavelength of observation with VINCI and MIDI is different, the quality of the calibrator can also change drastically between 2.2 and 10 microns. Fig. 5 shows the instrumental transfer function, covering several different array configurations during VLTI commissioning with the VINCI instrument. Trends of the instrumental transfer function will also be monitored for MIDI.

Quality Control, Instrument Trending and Monitoring

In the case of MIDI, we are still in the process of defining the list of QC parameters which best describes the status of the instrument and the quality of the observations. Using VINCI experience and the data from the first MIDI observations (commissioning and Service Mode observations), we are gaining knowledge about such instrument monitoring. Using calibrator stars from the *CalVin* list provides us with some objects which are observed several nights during each MIDI run. These objects allow us to detect any trends in the instrument and therefore identify any changes or systematic effects. Fig. 6 shows the instrumental transfer function measured over several nights.

Data packages

After each MIDI run, the full data set is processed. A package is created for each completed or terminated run. The data package follows the same structure as the other VLT instruments. We distribute all the raw data associated with the programme (acquisition on both telescopes, raw data on the fringe search, raw data on the fringe track and its associated calibration). Included in the package are the technical calibration data which are used to calibrate the science data. Concerning the astronomical calibrators, we decided to include in each package only the data associated to the astronomical calibrator requested by the PI. If the calibration of the science data requires more than one astronomical calibrator, the PI can request the data for additional calibrator stars from the Garching archive.

We also distribute product data when the data were processed successfully by the pipeline (FITS product, PAF file, and associated log file). If several calibrators were observed during the night we provide the instrumental transfer function measured on the calibrators.

Conclusion

MIDI is now fully integrated into the general science operations scheme of the VLT. Specific tools have been developed, particularly in the area of observation preparation, data quality control and instrument trending to deal with the specific aspects of interferometry. These developments will remain important as the VLTI Auxiliary Telescopes (Koehler et al., 2004) are installed as it will allow users to observe with the VLTI every night throughout the year. The publication of a follow-up *Messenger* article is anticipated, in which the overall VLTI science operations scheme and service mode philosophy will be discussed in more detail.

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