Preparing MIDI science operation at VLTI

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ABSTRACT

MIDI (MID-infrared Interferometric instrument) gave its first N-band (8 to 13 micron) stellar interference fringes on the VLTI (Very Large Telescope Interferometer) at Cerro Paranal Observatory (Chile) in December 2002. An lot of work had to be done to transform it, from a successful physics experiment, into a premium science instrument which is offered to the worldwide community of astronomers since September 2003. The process of "paranalization", carried out by the European Southern Observatory (ESO) in collaboration with the MIDI consortium, has aimed to make MIDI simpler to use, more reliable, and more efficient. We describe in this paper these different aspects of paranalization (detailing the improvement brought to the observation software) and the lessons we have learnt. Some general rules, for bringing an interferometric instrument into routine operation in an observatory, can be drawn from the experience with MIDI. We also report our experience of the first "service mode" run of an interferometer (VLTI + MIDI) that took place in April 2004.

Keywords: infrared interferometry, instrument operation, service mode.

1. INTRODUCTION

MIDI[1, 2] belongs to the first generation instruments of the Very Large Telescope Interferometer (VLTI), located at Cerro Paranal, Chile. The VLTI infrastructure has been built and is operated by the European Southern Observatory. MIDI has been built by a consortium of European institutes, led by the Max-Planck Institut für Astronomie (MPIA), Heidelberg, Germany. MIDI is a two-beam combiner instrument dedicated to N-band (8 to 13 micron) observations. Like any interferometric instrument, it produces raw data in the form of interference fringes.

For the astronomers who witnessed the early days of stellar interferometric experiments, such instruments usually had the reputation of "duct-tape-and-black-cardboard" makeshift optical setups, that could only be used by some "wizards" working (and sometimes living) on the site of the interferometer. The intention of ESO regarding MIDI, and the VLTI in general, is to offer an interferometric system to the widest possible community of astronomers and astrophysicists (that we call here the "users") who have not necessarily a deep knowledge how an interferometer works. Moreover, the maintenance of VLTI and MIDI is being transferred to the Paranal

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engineers who usually work on the Nasmyth or Cassegrain VLT instruments. Basically, using an interferometric instrument should be like using a single-telescope instrument of the VLT.

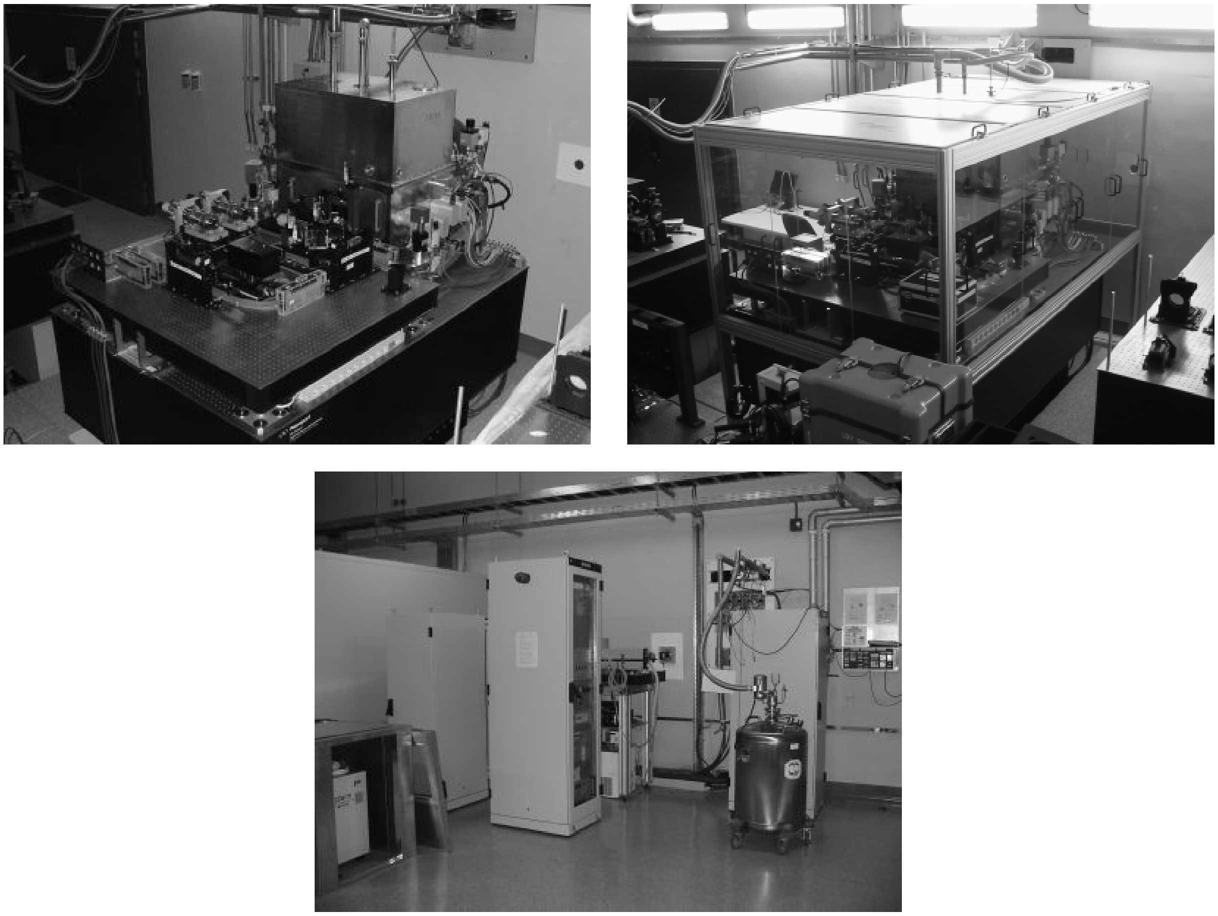

Fig. 1. MIDI as it has been assembled in the VLTI laboratory of Paranal, end 2003 (left) ; MIDI now in its thermal enclosure (right) ; ancillary equipment of MIDI (control electronics, LN_2 supply, closed-cycle cooler compressor, vacuum roughing pump, and artificial sources) in the “Combined Coudé” room, next to the VLTI laboratory.

2. HANDING OVER MIDI TO ESO

The transfer of knowledge of a complex instrument like MIDI, from the consortium to ESO, has been a long process scheduled over a few years. First, a VLTI instrument scientist has been appointed by ESO to follow the development of the VLTI instruments (MIDI and AMBER) by their consortia. Then, a MIDI instrument scientist, who is responsible for MIDI at Cerro Paranal, has been hired by ESO, but stayed 14 months at MPIA. There, he learnt the technical details of operation and maintenance of MIDI, including optics, cryogenics, electronics, and software. Finally, two ESO engineers, one for the hardware, another one for the software, have been chosen to ensure the maintenance of MIDI at Cerro Paranal. They started to be trained at the time of the Preliminary Acceptance in Europe (PAE) of the instrument.

3. THE “PARANALIZATION” OF MIDI

This awkward neologism defines the process for any new instrument to be absorbed within the Paranal operational environment. Instruments require a stable, non evolving, platform during development. On the other hand the observatory will evolve its operational concepts. The interfacing with the VLT environment leading to the “first light" (or "first fringes" for an interferometric instrument) is part of the AIV (assembly, integration, verification) and this is executed on the development platform. Following the early commissioning[3] (which is led by the consortium), paranalization activities are performed jointly with the consortium to achieve the final operational status of the instrument.

Paranalization is not necessarily a software only activity. In this article we will take to mean all activities undertaken on the VLT site to bring the instrument to its first fully operational common user status.

3.1. Hardware issues

The AIV of MIDI at Cerro Paranal was done by the MIDI consortium with the help of the whole ESO engineering staff. It lasted about four weeks. To be compliant with the Paranal environment, slight mechanical upgrades have later been necessary: for prevention of damage due to earthquakes (frequent phenomenon at Paranal), the electronics cabinets of MIDI have been tethered to the ceiling of the "Combined Coudé" room (Fig. 1, bottom) with steel cables, and blocked on the floor with hard stops. MIDI also had to comply with strict specifications regarding mechanical vibrations, heat dissipation, and acoustic noise. Thus, the "cold-head" of the helium closed-cycle cooler of MIDI had to be muffled by a foam-padded enclosure. A thermal enclosure (Fig. 1, right) had to be installed. It consists of a metallic structure supporting plexiglas panels that surround the MIDI table. The aim of this enclosure is to balance the temperatures of the different external MIDI parts by internal heat exchange. Tests recently done with a thermal camera tend to prove that MIDI, inside its enclosure, is compliant with the general VLTI instrument specifications (temperature equal to the ambient temperature +0.5/-1 °C).

The most critical point is the vibrations that are generated by the cold-head motion. Up to now, the level of vibration is out of specifications, though it doesn't have an impact on the quality of the data acquired with VINCI (when MIDI is not used, its closed-cycle cooler is still running. Hence, MIDI can quickly be switched back for operation at any time). However in the future, for accurate phase tracking and measurement with instruments like PRIMA,[5] the MIDI vibrations might be an issue.

3.2. Software issues

As any VLT instrument, MIDI is run through "observation blocks" (OBs) that are written by the users.[6] These OBs consist of a list of "templates". Each template is a script executed by the instrument, for which the user can specify the values of some parameters ("FITS keywords"). The file, associated to a template, that contains the list of keywords is called a "TSF" (Template Signature File). The automatic operation sequence associated to a template is coded in Tcl language. Applying the set of keyword values to the states (mechanical positions, detector parameters,...) of the corresponding devices of an instrument is called a "setup".

The main software paranalization task consisted in developing new templates for several reasons:

- Increase the efficiency of MIDI in terms of visibility measurement rate (the aim for the first observing period was one hour per calibrated visibility spectrum). For example, by having the telescope preset and the instrument setup performed simultaneously.
- Simplify the TSFs for the users, so they have a minimum number of keywords to set (see Sect. 4.3).
- Develop "intelligent" template sequence codes which, from a minimal set of keywords provided by the TSF, can set the right values for other keywords, corresponding to a logical instrument setup.
- Make configuration files with all the keyword values that are not supposed to be modified by the user or by the operator.
- Make MIDI FITS file headers compliant with the requirement of the pipeline (quick data processor) developed by the Data Management Division at ESO-Garching.
- Develop "maintenance templates" to monitor the "health" of the instrument (detector noise and linearity, transmission of the dispersive elements, etc...).

Besides the work on the templates, some modifications had to be done to the software, in collaboration with the MIDI consortium, to make the instrument more reliable (i.e., to avoid software crashes during an observation). The acquisition template has been modified to allow interactive operation (see Sect. 4.2). The observation template merges fringe exposure and photometry exposures (see Sect. 4.3), with the possibility to do a fringe search instead.

As a request from the Paranal Science Operation team, the real time display (RTD) of MIDI had to be redesigned for a better efficiency: during a fringe exposure, an "horizontal waterfall" shows the undispersed fringe envelope for each scan (OPD modulation to get an interferogram) that has been performed. This display is updated in real-time. Each pixel column represents the envelope of a scan (see Fig. 4, top). Also, some scripts have been adapted from other VLT instruments to MIDI, for automatically logging in a night report the description of the observations. These scripts compute the "open shutter" (photon-collecting) time for statistics, and check that the exposure files have been archived at the end of the night.

3.3. MIDI and the VLTI environment

A major task of the commissioning and paranalization of MIDI was to interface it with the VLTI environment. We describe here the important subsystems of the VLTI, and how MIDI interacts with them.

3.3.1. Telescopes

For the moment, the only available telescopes for MIDI are the 8.2-m Unit Telescopes (UTs) of the VLT. The 1.8-m Auxiliary Telescopes (ATs) of the VLTI are still under commissioning.

Each UT telescope is equipped with a tip-tilt correction system called "STRAP" (System for Tip-tilt Removal with Avalanche Photodiodes) located in the Coudé system, underneath the M9 dichroic (mostly reflecting the IR light to the VLTI optical train downstream). It consists of a quadrant avalanche photodiode array which feeds back the UT secondary mirror (M2) tip-tilt mechanism. When the loop is closed, the telescopes are said to be in "Coudé guiding" mode. The M2 motion is later offloaded to the alt-az telescope axes.

The sensitivity of STRAP is V=16. To get diffraction-limited images on MIDI, in normal seeing conditions, it is mandatory that STRAP is used. However, if the target to observed is fainter than V=16, it is still possible to perform "off-target Coudé guiding", provided a suitable guide star exists. This guide star must indeed be brighter than V=16, and closer than 1 arcmin from the target to be observed on MIDI.

Performing mid-IR observations requires to discriminate the faint stellar signal against a strong and variable background that mostly comes from the sky and optical train thermal emission. The standard technique, called "chopping", consists in tilting the M2 at high frequency.

Chopping against an empty part of the sky reduces the background signal to the zeroth order and normally removes the temporal background variations. An intensity gradient, sometimes strong, remains in the background-subtracted data. It is due to the light paths through the system which are slightly different for the "on" and "off" positions. An alternative would be the "nodding" technique, that consists in offsetting the alt-az positions of the telescopes to acquire a sky image. However, the possibility of nodding with MIDI, though implemented, has been discarded for normal operation, and only chopping is used on MIDI for background subtraction. Nodding is slower than chopping when used by the UTs + MIDI, and cannot follow the background fluctuations. With MIDI, the typical chopping frequency is 2 Hz, whereas the maximal nodding frequency is about 0.1 Hz.

In order to ensure beam overlap, MIDI has the possibility to offset the M2 mirror. This is actually done by offsetting the "XY-table" on which STRAP is mounted: offsetting the XY-table will correspond to an image shift on STRAP, and therefore to an offset applied on M2 to re-center the image (Fig. 2).

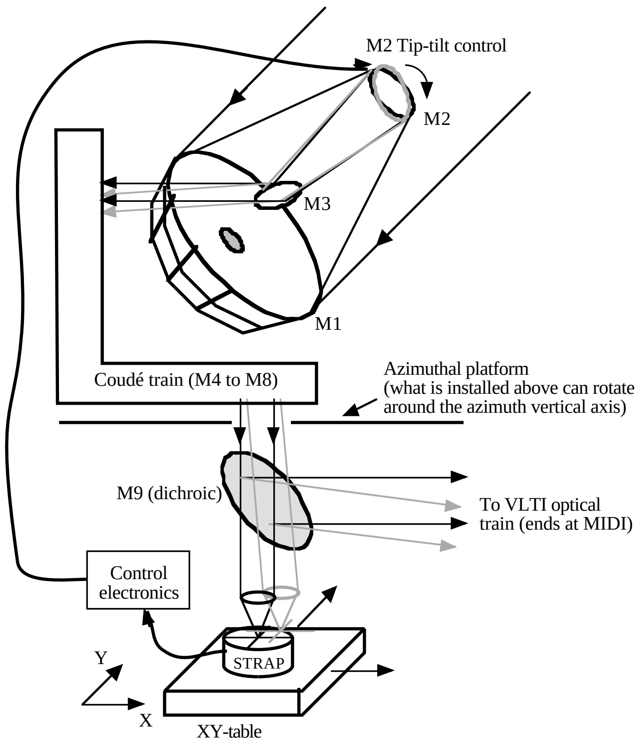

Fig. 2. Simplified schematic of a UT with its Coudé system for the VLTI. If an offset $(+x, +y)$ is applied to the XY-table on which the STRAP detector is mounted, the M2 will receive a tip-tilt in offset, and the beams along the optical axis of UT1 will follow the path represented by grey lines. Hence, MIDI will "see" a different region of the sky from this telescope.

3.3.2. Delay lines

With MIDI, two VLTI delay lines are used to compensate the optical path difference (OPD) between the two telescopes, from the incoming stellar waveplane to the instrument entrance. Each telescope has a dedicated delay line. One is at a fixed position, whereas the other one continuously moves in order to compensate the OPD for apparent sidereal motion.

Each VLTI delay line is based on a cat's eye optical design featuring a variable curvature mirror[7] (VCM) at its center. The aim of the VCM is, by modifying its radius of curvature, to perform a pupil transfer to a desired position, wherever the delay line carriage is. In the case of MIDI, the optimal pupil position is the "cold stop" that is located inside the cryostat right after the shutter. The advantages of transferring the pupil are:

- An optimal field-of-view (2 arcsec with the UTs). Fringes can be made from any target within this FOV.
- A reduction of the thermal background related to VLTI optics.

Currently, the VCMs are not used due to alignment problems. Nevertheless, MIDI already achieves good performance with the VCMs at fixed radii.

To compensate OPD drifts due to uncertainty of the array geometry, as well as atmospheric differential piston, position offsets can be applied at high rate to the moving delay line by an OPD controller. Up to now, the OPD controller directly receives commands from MIDI during MIDI operation in "Fourier mode" (see Sect. 4.1). In the future, a faster external fringe-tracker system (FINITO[8]) will be used with MIDI to perform coherent fringe integration.

3.4. Technical runs with one telescope only

Operating an interferometric instrument with one telescope only may sound like an oxymoron. However, the opportunity to get technical time with the Melipal telescope (UT number 3 of the VLT) around full Moon period (when VIMOS –VIsual Multi-Object Spectrograph–, at that time the sole instrument of Melipal, could not be used) in September 2003 was crucial to improve some aspects of MIDI. Besides the possibility to verify the acquisition system (off-target Coudé guiding, acquisition template execution, image quality checks), sky background exposures at different telescope altitudes have been recorded. A better knowledge of the properties of the sky background will help to optimize MIDI operation.

4. OFFERING MIDI TO THE COMMUNITY

As said before, one of our goals at ESO is to "popularize" interferometry among the community of astronomers and astrophysicists. MIDI has the advantage to be a real VLT instrument, using the same software environment. For ESO period 73 (covering observations from April to September 2004), the process of Call-for-Proposal, of "ESOFORM" proposal submission system (phase-1), of OB preparation in case of service mode (phase-2) for MIDI was the same as for any VLT instrument.

The peculiarity of MIDI comes from the way the instrument time has been offered: as one-hour slots ; each slot corresponding to a calibrated visibility spectrum to be measured (fringes on the science target, then on a calibrator), regardless of the correlated flux of the science target.

4.1. Offered modes

We offered only one possible MIDI mode (setup) for the observations in period 73:

- Dispersed fringes.
- NaCl prism dispersion (spectral resolution ≈ 30).
- Spectroscopic slit width = 0.52 arcsec on sky.
- "High-sensitivity" beam combiner (no photometric channels).
- Fourier fringe mode.

This mode dictated the way the observation template had to be designed. With this mode, the photometric channels of MIDI are not used. These photometric channels consist of beamsplitters taking 30% of the light from each beam before recombination, and focusing it on the MIDI detector, in order to sample temporal variations of intensity related to turbulence. In the high-sensitivity mode, the beamsplitters are not inserted in the optical path of the beams before combination.

In the absence of photometric channels, two exposures are taken with an optical setup (beam combiner, prism, slit) similar to the one used for the fringe exposure: one exposure with the beam A only, then a second exposure with the beam B only. These exposures (included in the fringe exposure template) allow to derivate the visibility from the correlated flux that has been measured by the fringe exposure.

The fringe exposure is performed in "Fourier mode": the scan is a few $\bar{\lambda}$ long, typically 80 μm. A Fourier transform can be applied to each spectrum channel of each scan to compute the fringe contrast at a given wavelength. Usually, a little less than 200 scans are needed to compute raw visibilities with a good signal-to-noise. To get rid of the sky background in fringe mode, MIDI uses a trick related to its optical design: the two interferometric channels at the exit of the half-transparent combiner plate are in phase opposition. Since the sky background in the two channels is strongly correlated, subtracting the signals from the interferometric channels will cancel out the background and enhance the fringe signal.

Two VLTI baselines were offered with the single MIDI mode: UT1-UT3 (102.4 m on ground) and UT2-UT3 (46.6 m on ground), at different dates. The user also had the possibility to schedule an hour angle range for his/her observation, if he/she wants to measure a visibility in a specific region of the (u, v) plane. The baseline and hour angle constraints had to explicitly be indicated in the name of the OB during phase-2 preparation (see Sect. 4.3). Nevertheless, these parameters should be part of the standard constraint set in the next version of the "P2PP" tool used to edit OBs.

A limiting correlated magnitude N=2.25 (equivalent to 5 Jy at 12 μm) was given for any target to be observed in the offered mode. This limit has been decided after observations of faint calibrators during paranalization runs.

4.2. MIDI in operation

The paranalization of the template sequences of MIDI has established the following operation steps, in order to obtain a raw visibility:

1. **Preset:** Slew the telescopes to the target position on sky, and slew the two delay lines. Bring them in "tracking" state (pre-defined sidereal trajectory. Note that one delay line will remain fixed, while the other one moves in tracking state). Bring telescopes in Nasmyth, then Coudé guiding (tip-tilt correction). During the preset, the setup of MIDI (device motions) is performed.

2. **Acquisition:** Adjust pointing, so the beams from the target will overlap inside MIDI and can interfere. This is done by an iterative process:

   (a) An exposure in imaging mode (full field, 84 mas/pixel) with chopping is taken (Fig. 3, top). A filter, centered at λ=8.7 μm with FWHM=1.75 μm, is used to reduce the sky background noise. The MIDI software computes the position of the object for each beam, and calculates an error vector according to the position of the "reference pixels" of the detector. If these error vectors are null, the beams are supposed to overlap, once the beam combiner plate of MIDI is slid in.

   (b) If the operator is not satisfied with the error vectors (that should typically be less than one pixel long), an offset, computed from the vectors is applied to the XY-tables of the Coudés. The result is an offset applied to the M2 mirror of each UT. An exposure is taken afterwards (see a).

   (c) The previous step is repeated until the error vectors are small enough. Typically, it takes three iterations to get a correct beam overlap.

3. **Fringe search:** The operator has to indicate an OPD starting offset and a length for the OPD search. After each scan, the OPD offset is increased and sent to the VLTI OPD controller which will forward it to the delay line in motion (i.e., in sidereal tracking). The fringe amplitude as well as the current OPD offset are displayed (Fig. 3, bottom). When the offset corresponds to the zero-OPD, the fringes are found. The presence of a peak in the amplitude plot indicates the fringe detection.

4. **Fringe record:** The operator sets the OPD starting offset at the previously found OPD offset of the peak, and starts the fringe exposure (Fig. 4, top) which consists in a series of $\approx$ 200 interferograms obtained by OPD scans (moving the piezo-mounted roof mirror of the MIDI warm optics). Currently, MIDI is used in self fringe tracking mode: the center of the fringe packet in each interferogram is computed for each scan, and is converted into an offset sent to the VLTI OPD controller.

5. **Photometry:** Right after the fringe exposure, two exposures are taken with the previous instrument setup, except that only the shutter for the beam A of MIDI is open for the first exposure, then only the shutter for the beam B is open for the second exposure (Fig. 4, bottom).

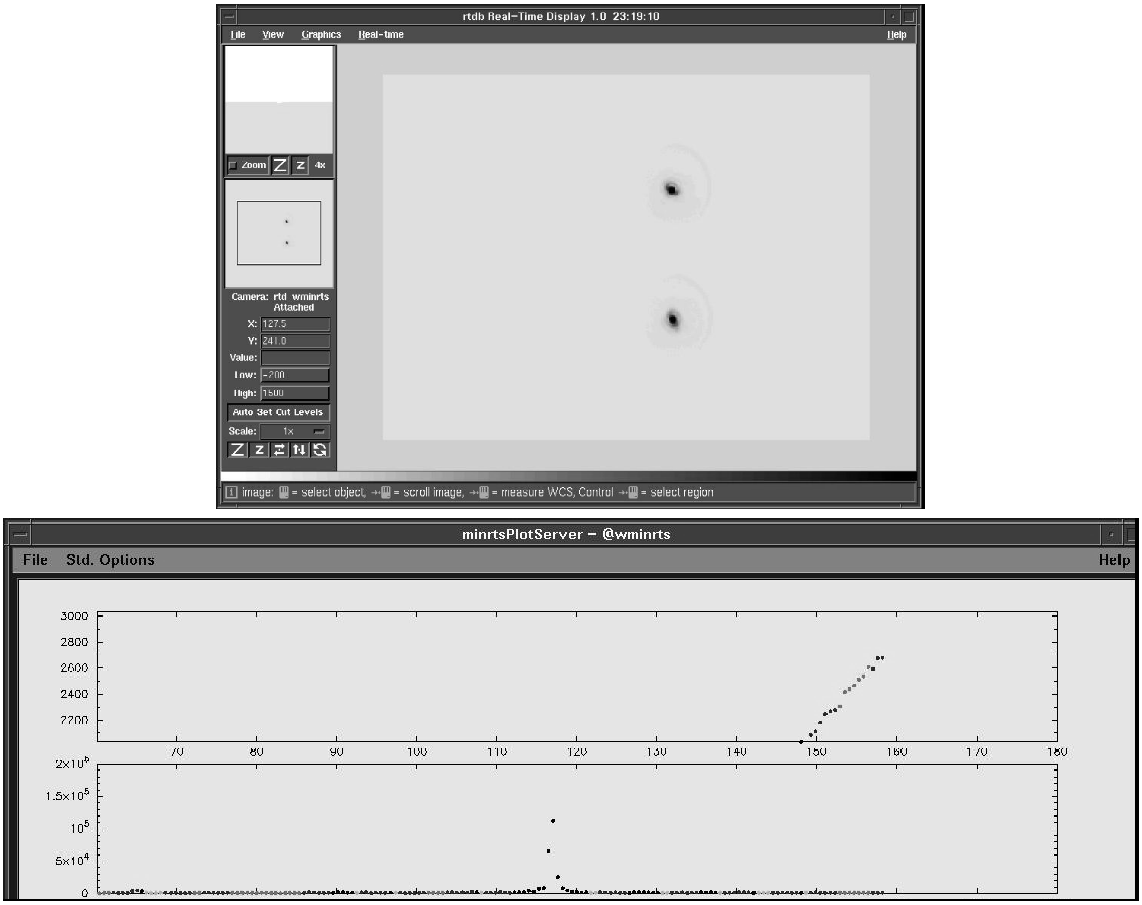

Fig. 3. MIDI operation panels (in negative) displayed during an OB execution (part 1). Top: acquisition (imaging mode, object seen from the telescopes separately) ; bottom: fringe search (OPD offset vs. time is plotted at the top, fringe amplitude vs. time is plotted at the bottom. At zero-OPD, a fringe peak appears).

Notice that due to the design of the detector control software of MIDI, the number of frames in an exposure, whatever its purpose is (acquisition, fringe search, fringe record, photometry), is fixed by advance and can not be changed "on-the-fly" during the exposure. This limits the flexibility of MIDI operations.

The paranalization runs have also allowed to find convincing evidence of the presence of deceiving "ghost" fringes, likely due to internal reflections of MIDI. These ghost fringes are located at $\pm$ 3.4 mm from the real zero-OPD. For a bright star (>100 Jy at 12 μm), they are easily detectable and noticeable by their contrast, much lower than the main fringes. To determine the actual zero-OPD, we usually start the night by doing a large fringe search on a bright object to detect the main fringes and the ghosts.

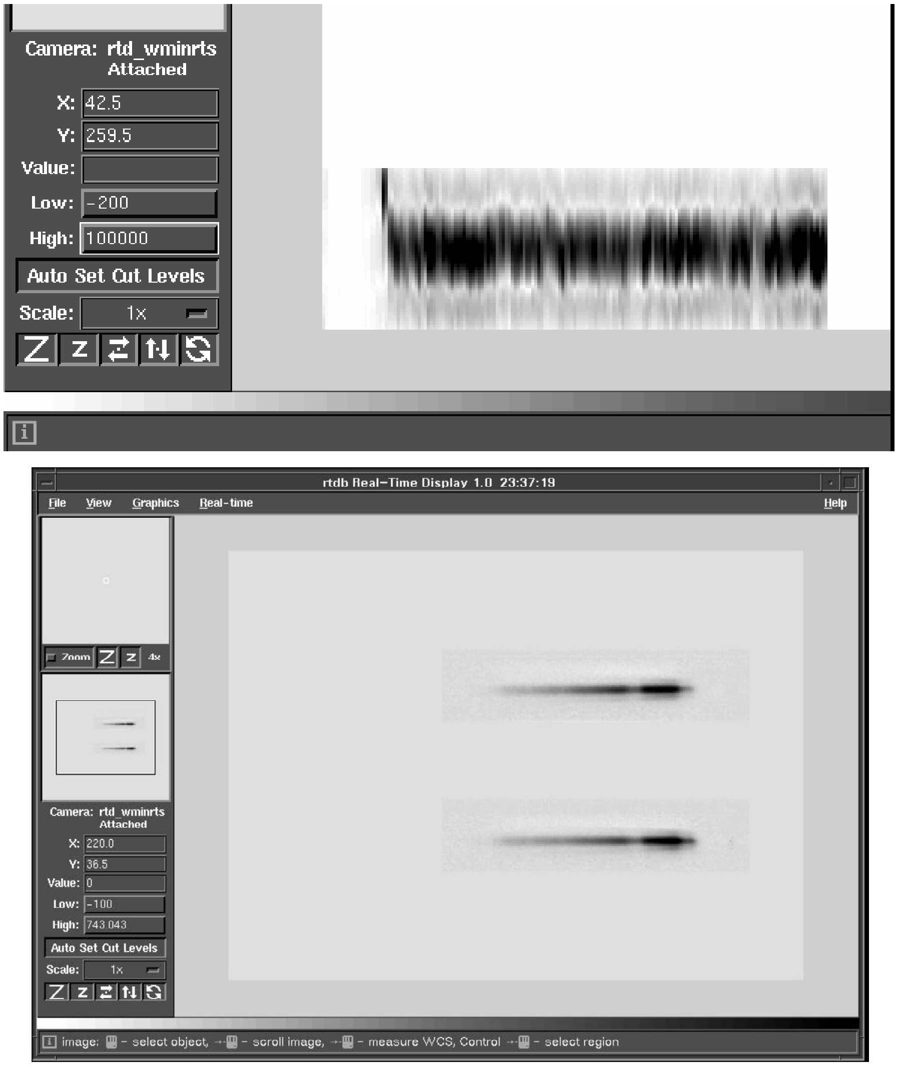

Fig. 4. MIDI operation panels (in negative) displayed during an OB execution (part 2). Top: fringe record (each column of pixel represents the fringe packet envelope of a 80-μm scan) ; bottom: photometry (spectrum of the object from one telescope only, seen through the two interferometric channels of MIDI).

4.3. Phase-2 preparation

For ESO period 73, twelve program proposals with MIDI have been accepted for service mode by the ESO Observing Programmes Committee (OPC). They correspond to 71 calibrated visibility points to be measured by the Paranal Science Operation team. For each point, a science target OB and a calibrator OB have to be made by the user from his/her institute, using the ESO P2PP tool. P2PP automatically downloads the "instrument package", i.e. the set of TSFs, the instrument summary file (listing the allowed values for the keywords), and the verification scripts (EVMs) for MIDI.

The TSFs have been written during paranalization to be as simple as possible for a user who is not familiar with interferometry. However, some keywords in the TSFs are hidden from P2PP for the user, but visible for the operator (e.g., preset done or not, fringe search only or not, OPD offset, detector integration time, etc...)

The sequence that the user has to define consists of an acquisition template (*MIDI_starintf_acq*) for which the user can specify the Coudé guiding mode (either on or off the MIDI target), and the coordinates of the guide star (if required). Following is an observation template (different for the science target and for the calibrator: either *MIDI_starintf_obs_fringe_sci* or *MIDI_starintf_obs_fringe_cal*). These templates perform fringe search, fringe record, and photometry exposures. For these templates, the user has no keyword value to specify. However, due to a P2PP bug, a dummy keyword, seen in P2PP, had to be added to the observation templates!

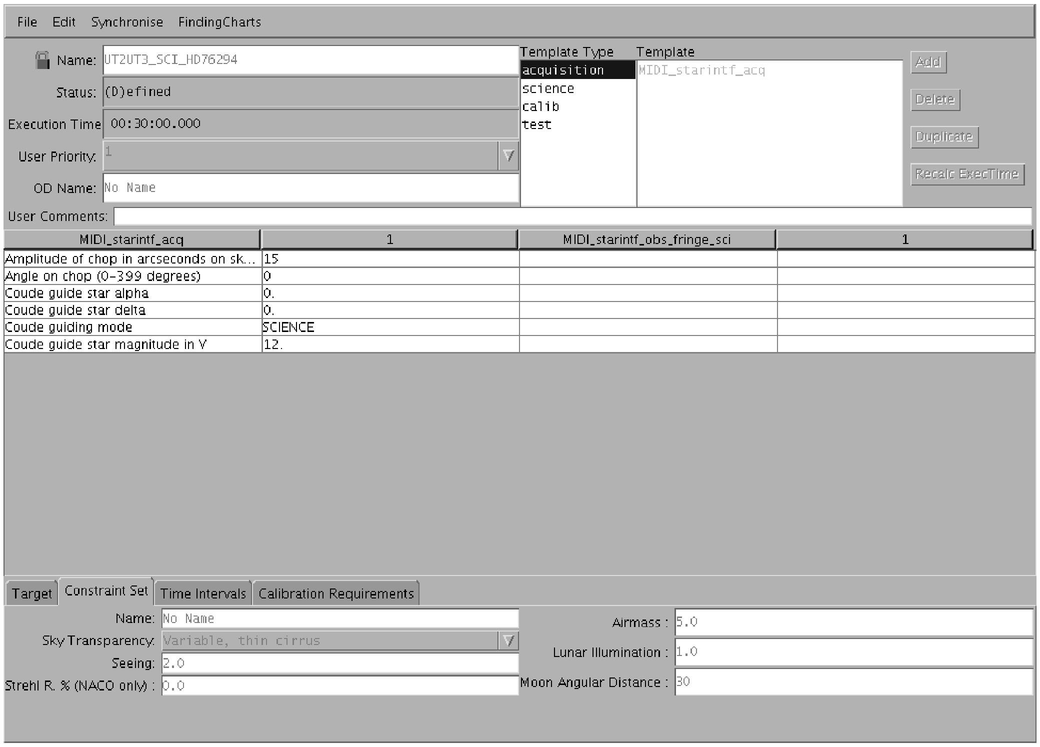

Fig. 5. Example of a MIDI OB written with P2PP, illustrating its simplicity. A dummy keyword had to be introduced later in the observation template (right hand), and does not appear on this picture (empty list of keywords).

5. THE FIRST SERVICE MODE AND VISITOR MODE RUNS WITH MIDI

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The first MIDI run started on 8 April 2004 in the evening and ended on 12 April 2004 in the morning. The baseline was UT2-UT3 (Kueyen and Melipal telescopes). Three and a half nights were dedicated to service mode, and half a night for visitor mode. The operation in service mode was quite smooth: a total technical downtime of 4 h 15 min had been logged, on a total of 35 h 37 min of dark night, which is satisfying for a first run. The main cause for the time loss was related to the electronics of the Coudé systems. During this service mode run, 30 calibrated visibilities, rated "A" (fully within specifications) or "B" (almost within specifications) have been obtained, proving the efficiency of MIDI in operation. Due to the fact that many users wanted to have their objects observed by the middle of the night, we ended after two nights of service mode with no OBs to be executed at the beginning of the night! So, UT2 was used for observations with its Nasmyth instruments UVES (UV/visible Echelle Spectrograph) and FLAMES (Fibre Large Array Multi-Element Spectrograph), while UT3 was used for technical tests with MIDI, as it has already been done in the past (see Sect. 3.4).

The visitor run lasted just half a night (before resuming the service mode). As the only target of the visiting astronomer was found to be over-resolved (visibility ≈ 0), we "lent" UT2 to UVES again, while the visiting astronomer was allowed to take MIDI images of his target with UT3 only, using the acquisition template with different filters, because of the scientific interest these data may have.

These examples may look anecdotal but perfectly illustrate the flexibility of the VLT(I) system as it has been designed: it is possible to seamlessly switch from the interferometric mode to independent telescope instruments. The procedure to hand over a UT to the VLTI only takes a little less than 15 min, which is quite short, considering the complexity of the system.

6. CONCLUSION

We have demonstrated, through ESO-standard service mode, that an interferometric instrument can be very simple to use for any astrophysicist wishing to get visibility points on the celestial objects he/she is studying. The usual difficulties related to interferometry (getting fringes, mostly) have been delegated to the operation team at Paranal. This operation team is backed by the engineering team, in order to have a productive and reliable instrument, available at any time.

In the future, however, the user will have a little more flexibility regarding the possible modes. For period 74, the grism mode (giving a spectral resolution $R \approx 230$) has been offered. It should also be possible to select the spectral filter used for the acquisition template (imaging), if, for example, the object features a strong absorption around 8.7 μm.

The main challenge of paranalization was the scarce availability of the UTs that are indeed heavily requested to be used with their Nasmyth or Cassegrain instruments. We took the opportunity to have sometimes an idle telescope to continue the paranalization of MIDI, as far as we could. It is important to notice that any interferometric instrument, to be offered in service mode, should be as simple as possible for the user. Rather than showcase all the possibilities of the instrument as soon as it is open to the community, a minimum set of modes, that have been proven to be reliable and to yield valuable science results, should be offered.

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