VLTI MIDI SCIENTIFIC OBSERVATION PROCEDURES:
Synergy between MIDI and GENIE - the MIDI nuller

Eric J. Bakker(1), **Frank Przygodda**(2), **Olivier Chesneau**(2), **Walter Jaffe**(1)

(1)Leiden Observatory
University of Leiden, P.O. Box 9513, NL-2300 RA Leiden, The Netherlands
bakker@strw.leidenuniv.nl, jaffe@strw.leidenuniv.nl

(2) Max-Planck-Institut für Astronomie
Königstuhl 17, 69117 Heidelberg
przygodd@mpia-hd.mpg.de, chesneau@mpia-hd.mpg.de

ABSTRACT

The first science instrument for the **V**ery **L**arge **T**elescope **I**nterferometer, the **Mid**-infrared **I**nstrument (MIDI), will be commissioned in November 2002 with anticipated first fringes during that commissioning run on the 40-cm Siderostats and the 8.2-meter Unit Telescopes. In this paper we describe scientific observation procedures developed for MIDI and describe how an observation run with the instrument is foreseen. Since the scientific observation procedures are still under development, this paper reflects the situation as it stands in August 2002. In the discussion we suggest how the synergy between MIDI and GENIE can be exploited through a possible instrument referred to as the MIDI-nuller.

MIDI is being built by a consortium lead by the Max Planck Institute for Astronomy (MPIA Heidelberg), with contributions from among others ASTRON (Dwingeloo, The Netherlands), Leiden Observatory, Kiepenheuer-Institut für Sonnenphysik (Freiburg), University of Amsterdam, University of Meudon, and the University of Groningen.

INTRODUCTION

The **V**ery **L**arge **T**elescope **I**nterferometer (VLTI) is entering a phase in which significant amount of scientific output is expected. The 2-micron 2-way beam combiner, the **V**LTI **IN**terferometry **C**ommissioning **I**nstrument (VINCI), is commissioned. The 10-micron 2-way beam combiner MIDI and the 2-micron 3-way **A**stronomical **M**ulti **BE**am **R**ecombiner (AMBER) will be commissioned in November 2002 and spring 2003 respectively.

In this paper we discuss the scientific operation procedures developed for MIDI [1]. The scientific operation procedures is a set of pre-defined modes, which has been developed for the instrument and is supported by the consortium. Additional modes may be added in the future after evaluation of the instrument performance on site during the commissioning runs.

We will first briefly describe the MIDI instrument and its functionality. Then the software architecture and how the software modules interact with the ESO hardware and software environment will be explained. This identifies the interfaces of the observation procedures with other systems and defines the boundaries to within it can operate. After this we focus on the scientific operation procedures for MIDI as they are in August 2002, followed by a presentation of some of the calibration procedures that are vital for the successful scientific operation of MIDI. Finally we discuss MIDI operation procedures in the context of the GENIE program. Identity the synergy and suggest a possible route to exploit this synergy.

A more extensive paper on MIDI observation procedures will be presented at the SPIE 2002 conference in Hawaii [2].

THE MIDI INSTRUMENT

MIDI is designed as a beam-combining instrument for the mid-infrared spectral range. It provides the coherent combination of two input beams. Interferometry at the mid-infrared wavelength has to overcome special problems. The main difficulty is the huge thermal sky background, which also varies in time. In addition to this the thermal emission of the instrument itself plays a role. To reduce this as good as possible, the main parts of the optics are placed in a Dewar and cooled down to a temperature of 40K.

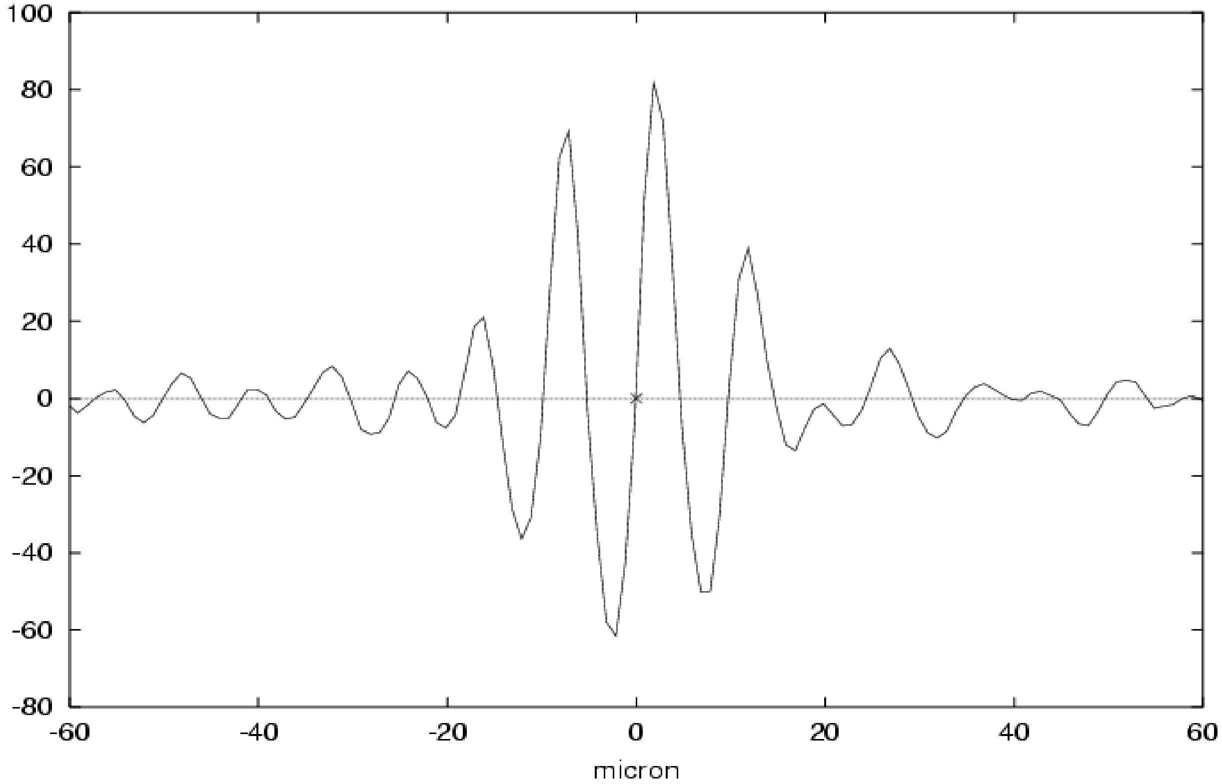

Fig. 1 Difference between the two interferometric output channels during an optical path difference scan of 120 µm across the zero position. A broadband source was used for this test (real MIDI data, y-axis in counts).

HARDWARE

Each beam transmitted by the VLTI infrastructure (telescopes, delay lines, beam compressors etc.) is passing at first a small instrument-internal delay line. These piezo driven delay lines allow a fine adjustment of the optical path for fringe tracking and scanning. Afterwards the light is entering the cold Dewar and goes through a cold pupil and a cold field stop before it is reaching the beam-combining unit. In this unit, the coherent combination takes place by superposing both beams at a 50%:50% beam splitter surface. The two resulting interferometric output channels are imaged on the detector. Instruments using this principle for the combination of the beams are so-called ‘‘Pupil Plane Interferometers’’. The measurement of the visibility is realized by modulation of the optical path length in one beam by using one of the small delay lines. Doing this, constructive and destructive interference occur temporally separated in the interferometric output channels. The contrast is proportional to the object visibility for a given baseline. Due to non-avoidable internal coherence loss of the incoming beams the contrast is never 100% even for point sources and must be calibrated therefore.

At the zero-OPD position (OPD = Optical Path Difference) both interferometric beams have the same intensity. This is the result of the optical layout of the beam-combining unit. Fig. 1 shows the difference in intensity of one interferometric output channel compared with the other during an OPD-scan of 120 µm across the zero position (in counts).

Finding the zero-OPD position and scanning the interference pattern (the "Fringe Packet") has to be performed by a complex controlling system. This system has to read the signal on the detector, to analyze it in real time and to drive the delay lines properly. Since the coherence time of the atmosphere at the mid-infrared range is about 100 ms, the correction must be done on a shorter time scale.

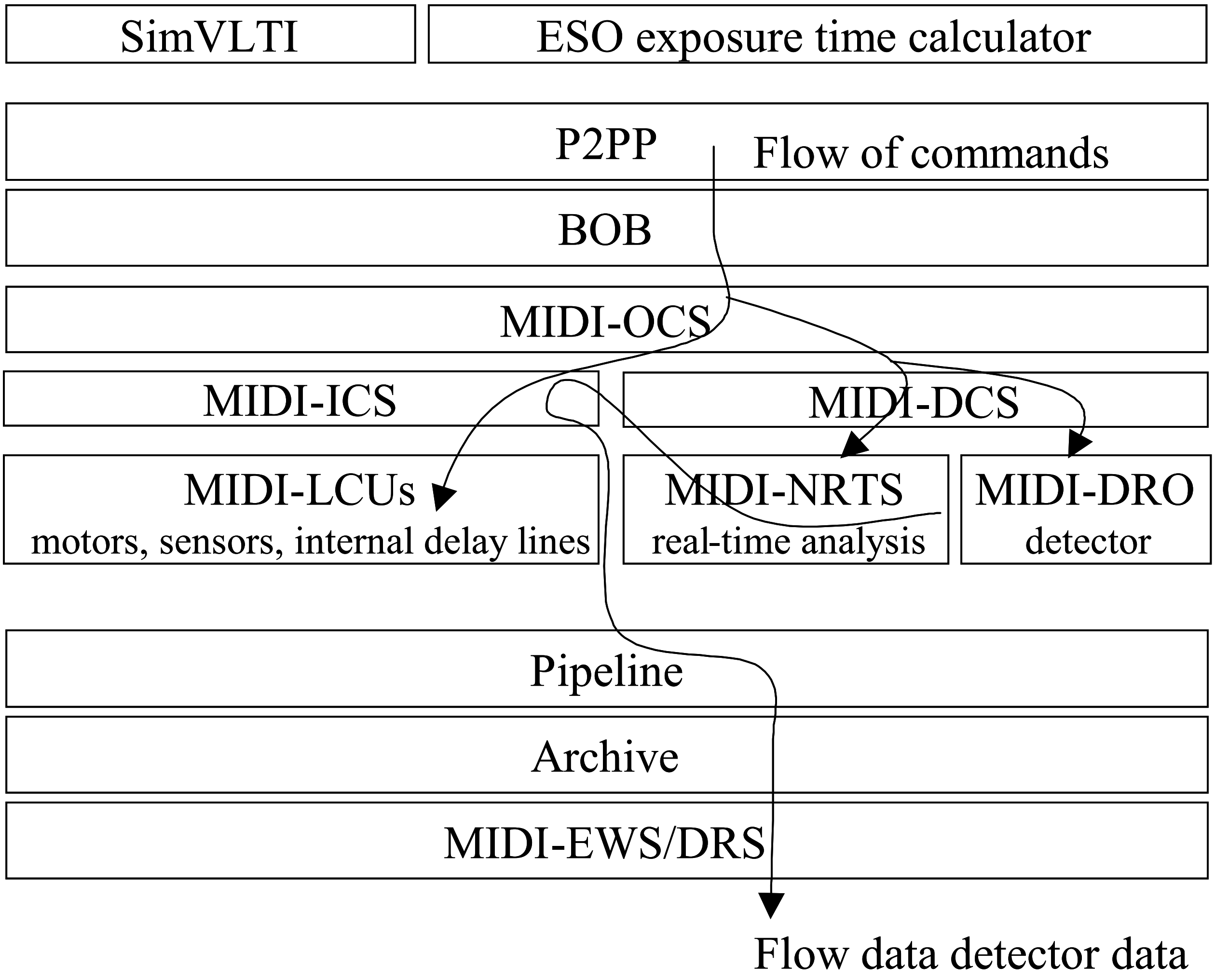

Fig. 2: MID software structure. Commands are on a high level defined by the astronomer, and detailed out by underlying software modules, to reach the motors, sensors, detector and finally the data analysis.

SOFTWARE ARCHITECTURE

MIDI software is largely developed according to ESO standards [3] with some deviations due to the special nature of MIDI. An overview of MIDI software is presented in Fig. 2 and can best be described as follows.

In the preparation phase the astronomer can use SimVLTI [4] to compute the expected visibility based on the selected baseline, time of observation, and characteristics of the science source. Additional tools are available to predict the exposure time for a given signal-to-noise ratio. The expected visibility and the expected exposure time are sufficient to prepare the observations with ‘‘**P**hase **2** **P**roposal **P**reparation’’ (P2PP). The astronomer fills in templates using the P2PP interface at his office location and as a result fully defines the observation procedure for MIDI at Paranal in that manner. The result of P2PP is an **O**bservation **B**lock **D**escription (OBD), which is imported in the **B**roker of **O**bservations **B**locks (BOB). In general P2PP runs at the astronomers office location, while BOB runs on the instrument workstation at Paranal.

Operations with MIDI at Paranal are started from BOB, which runs template sequencer scripts and sends the commands to MIDI **O**bservation **C**ontrol **S**ystem (MIDI-OCS). MIDI-OCS defines exposure schedules, monitors the MIDI subsystems, and communicates with the VLTI telescopes and VLTI delay lines. Commands are sent to the MIDI **I**nstrument **C**ontrol **S**ystem (ICS) and the MIDI **D**etector **C**ontrol **S**ystem (DCS). Whereas the latter compromises two parts: an adaptation of the **GE**neric **I**nfra**R**ed **S**oftware system (GEIRS) and a data archiving and data quality analysis system referred to as the **N**ear-**R**eal **T**ime **S**ystem (NRTS).

NRTS receives both the raw data from GEIRS and the scheduling information (delay lines, piezo etc.) from one **L**ocal **C**ontrol **U**nit (LCU), merges this information in FITS files, and forwards the data to the Instrument Software for later submission to the online archive and off-line reduction within the ESO ‘‘pipeline’’. The pipeline is non-interactive. To allow the astronomer to inspect and reduce the raw data in greater detail, the off-line reduction package **E**xpert **W**orkbench **S**tation (EWS) will be available to compute visibilities from the raw archived data.

SCIENTIFIC OPERATIONS MODES

The scientific operation modes for MIDI can be divided in two categories: those in which the light is dispersed and wavelength depend fringes are detected, and those in which the light integrated over the wavelength band is used. In both cases the MIDI piezo provide modulation of the signal and the VLTI main delay lines compensate for the Earth rotation. Fringe finding and tracking combines the optical path differences introduced in the system by the VLTI main delay lines, the MIDI translation stage, and the MIDI piezo. Fringe finding and tracking is done on-line for which a number of alternative fringe tracking algorithms for faint source science (or for low visibility sources) will be implemented in the MIDI software.

Non-dispersed Fourier fringe tracking

If only a spectral filter is inserted in the optical path, but no dispersive element (grism or prism), MIDI is capable of real-time fringe tracking. A MIDI internal piezo modulates the optical path according to a user-defined pattern (saw tooth, step function etc.) with user-defined stroke (total optical path length range). The position of the central peak of the white light fringe packet is computed and the offset of the delay line is updated such that the new optical path length stroke covers the predicted center of the white light fringe. This mode is referred to as the "**non-dispersed Fourier fringe tracking mode**". It is foreseen that once MIDI performance has been assessed during the commissioning runs an advanced fringe tracker will be implemented.

Dispersed Fourier fringe tracking

MIDI has been designed to work with a dispersive element. The prism provides a spectral resolution between 20 to 30, whereas the grism provides a spectral resolution of 230. If no dispersive element is placed in the optical path of the system, the two interferometric channels, I_1 and I_2, are detected on several pixels each. In the case that a dispersive element is in the optical path, the light is spread over an elongated strip on the detector. More advanced fringe tracking algorithms can be applied in this case. This mode will be referred to as "**dispersed Fourier fringe tracking mode**".

External fringe tracking

Once the dual feed phase referenced VLTI facility Phase Referenced Imaging and Micro-arcsecond Astrometry (PRIMA) [5], or fringe tracker Fringe-tracking Instrument of NIce and TOrino (FINITO) [6] will be available, fringe finding and tracking can be accomplished externally from MIDI, and allows for coherent integration of the detector signal for faint and low visibility sources. This mode of operations of MIDI will be referred to as "external fringe tracking mode", which can be in dispersed or non-dispersed mode.

CALIBRATION MODES

A number of calibration modes can be distinguished. Most important are the instrument calibration through the observation of a calibrator source. The other important calibration is the correction for thermal background radiation.

Wavelength calibration

Wavelength calibration with MIDI is required if one wants to make use of the prism or grism. The grism (with a relative high resolution of 230), as well as the prism (with a lower resolution between 20 and 30) can be calibrated by using the absorption line spectrum of two foils offered by the filter wheel of MIDI. The observation mode corresponding with the wavelength calibration is referred to as "**wavelength calibration mode**".

Coupling coefficients

The relative strength and correlation between the two output-beams of the beam combiner depends also on the flux ratio in the two input channels which is not necessary stable. For monitoring the coupling coefficients between input and output signals the flux of the incoming beams can be partly bypassed around the beam combiner and send directly to the detector. The observation mode corresponding with measuring the coupling coefficients is referred to as "**photometry calibration mode**".

Instrument calibration

The most important calibration is the one of measuring the visibility of a calibrator of known visibility, and to determine the instrument transfer function. This instrument transfer function must then be applied to the science source in order to compute the absolute visibility from the measured un-calibrated visibility. Observations with MIDI are structured in sequences referred to as **M**ultiple **O**bject **S**ingle **O**bservation **B**locks (MOSOB). Such a sequence contains a visibility measurement of a calibrator, a science source, and a second calibrator. This observation mode is referred to as "**instrument calibration mode**". This scheme of observation is defined in two phases. In first phase, the calibrators (one or two) and the science source are all three acquired and accurate coordinates are measured for these sources for the specific telescope condition and instrument configuration. These coordinates and the telescope configuration (mirror and adaptive optics settings) are stored for later use. The second phase is fringe tracking on the two calibrators and science source. Source acquisition can be fast since the stored telescope configuration is used and this will position the source at exactly the requested position on the MIDI detector.

Background calibration

One of the greatest challenges faced by MIDI is the correction for the thermal background (both from the atmosphere and from the telescope optical train). MIDI offers at least two methods to correct for the thermal background. These modes will be referred to as "**virtual chopping mode**" and "**real chopping and nodding mode**". The use of real chopping and nodding leads for each chop or nod to a loss of the fringe. The fringe of the source has to be reacquired after the telescope chops or nods back to the science source. An alternative approach is to use virtual chopping and correct for the background through interpolation of the background signals derived from two additional pinholes on both sides of the science pinhole.

A triple pinhole can be inserted in the optical path of MIDI. The science light passes through the central pinhole and produces a signal at the two interferometric output channels I_1 and I_2. On both sides there is an additional pinhole, which only contains background radiation. In the **virtual chopping mode**, the MIDI software determines the background radiation from the two outer pinholes, which only contain the background radiation and interpolates to compute the background level at the position of the science source.

Advanced operation modes for MIDI are foreseen after the instrument performance has been demonstrated at Paranal. Among the improved performance modes currently under discussion are improved rejection of the background radiation and water vapor effects by developing dedicated nodding and chopping modes, and faint source fringe tracking.

DISCUSSION: MIDI IN THE CONTEXT OF GENIE: THE MIDI NULLER

MIDI scientific operation procedures are in a phase of definition and development. The modes are defined as described and tested in the laboratory in Heidelberg. The next phase is testing these concepts during commissioning. This will surely lead to major changes and improvements. This paper therefore only gives a status report on our current thoughts about the scientific operation procedures, but the reader is advised to see if later papers devoted to this topic supersede this one.

Major challenges for the MIDI scientific operation procedure will be related to decreasing the time overhead for acquisition (which is currently believed to be 10 minutes for the Unit Telescopes), correction for the thermal background of the atmosphere and the VLTI infrastructure, and possible corrections for fluctuations in the signal due to variability in the water vapor content in the atmosphere and delay line tunnel.

How can this be related to the GENIE project? First, if GENIE really wants to be a technology demonstrator for DARWIN, then the most promising exercise would be to build GENIE for the same spectral range as DARWIN (6-18 micron). Give the atmospheric windows available; the greatest push to DARWIN required technology would be given if GENIE concentrates on the 10-micron band (most noticeable integrated optics and cryogenics). From the point of view of scientific operations, GENIE will face the same challenges as MIDI: thermal background and variability in water vapor in the atmosphere and delay line tunnel. There can be significant synergy between MIDI and GENIE; possibly GENIE could be an extension of MIDI, referred to as the MIDI-nuller. For a better understanding of required changes we first point out the most important differences between MIDI and a real nulling instrument.

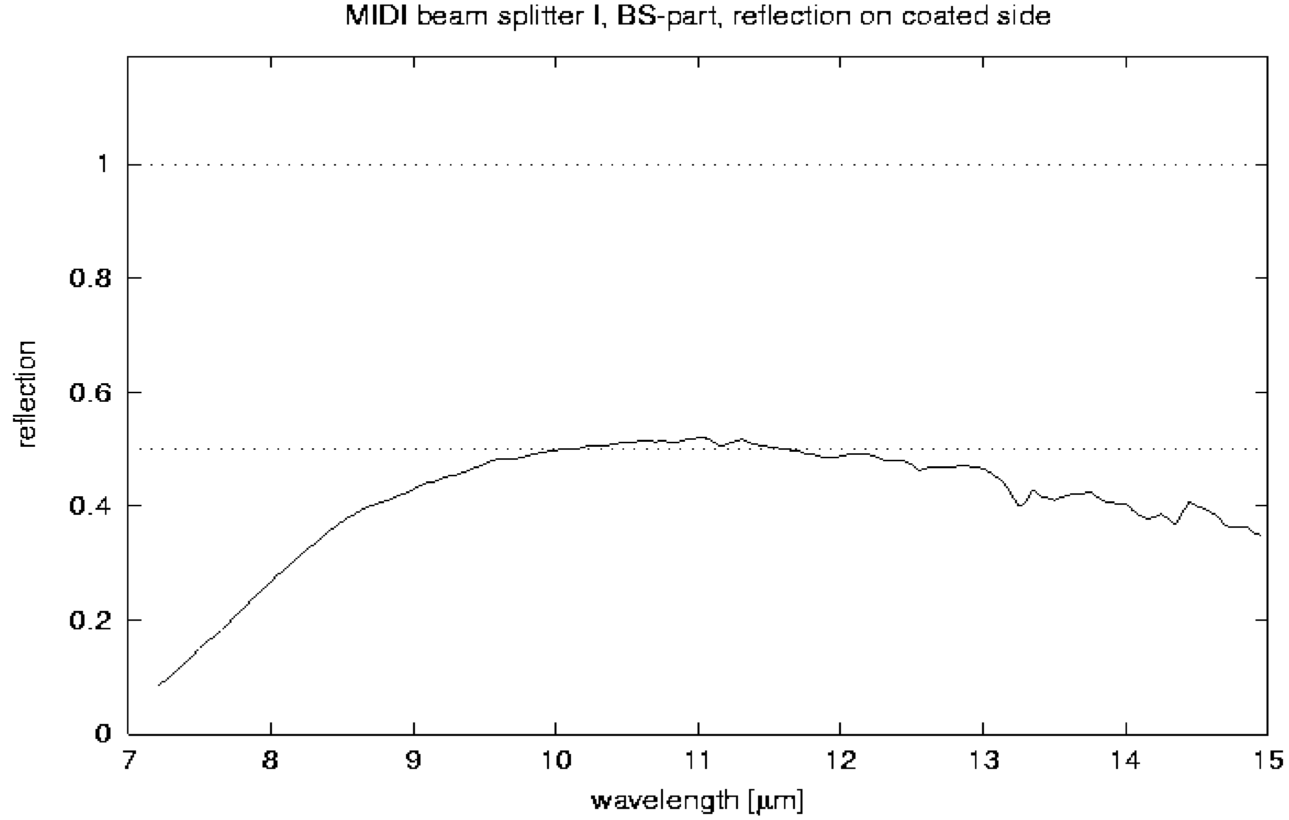

Fig. 3: Wavelength dependency of the reflection at the MIDI beam splitter plate over the N-band.

Properties of the beam combining unit

As discussed above the optical properties of MIDI's beam combining unit lead to equal intensities in both interferometric channels at the zero OPD-position. The maximum destructive (and also the constructive) interference is placed a quarter of the average wavelength aside. Since a fraction of a wavelength is a chromatic quantity, cancellation of the light cannot be performed for all wavelengths at the same time. In the case of MIDI a broad band nulling is only possible, if a compensating achromatic phase shift can be introduced to the input beams.
Another problem is the wavelength dependent transmissivity and reflectivity of the beam splitter plate itself. Over the N-band these quantities vary by about 25% (see Fig. 3). This has also to be improved or at least compensated to achieve a broadband nulling.

Requirements on stability

To get a deep and stable broad band null, the light of the two input beams must be very stable with respect to phase variations, dispersion and - in particular at 10 µm - background fluctuations. As described in the sections above, this requires a huge effort on controlling and calibration. For example: Within a time of about 100 ms the phase variations are almost 1 radian rms. Since for nulling the stability must be even much higher than for "simple" visibility measurements, the controlling must be performed in a very small fraction of the coherence time. This implies short integration times and therefore a reduction of intensity on the other hand. A possible way out is to track the phase variations in another spectral range, but also this needs enough intensity at the used wavelength.

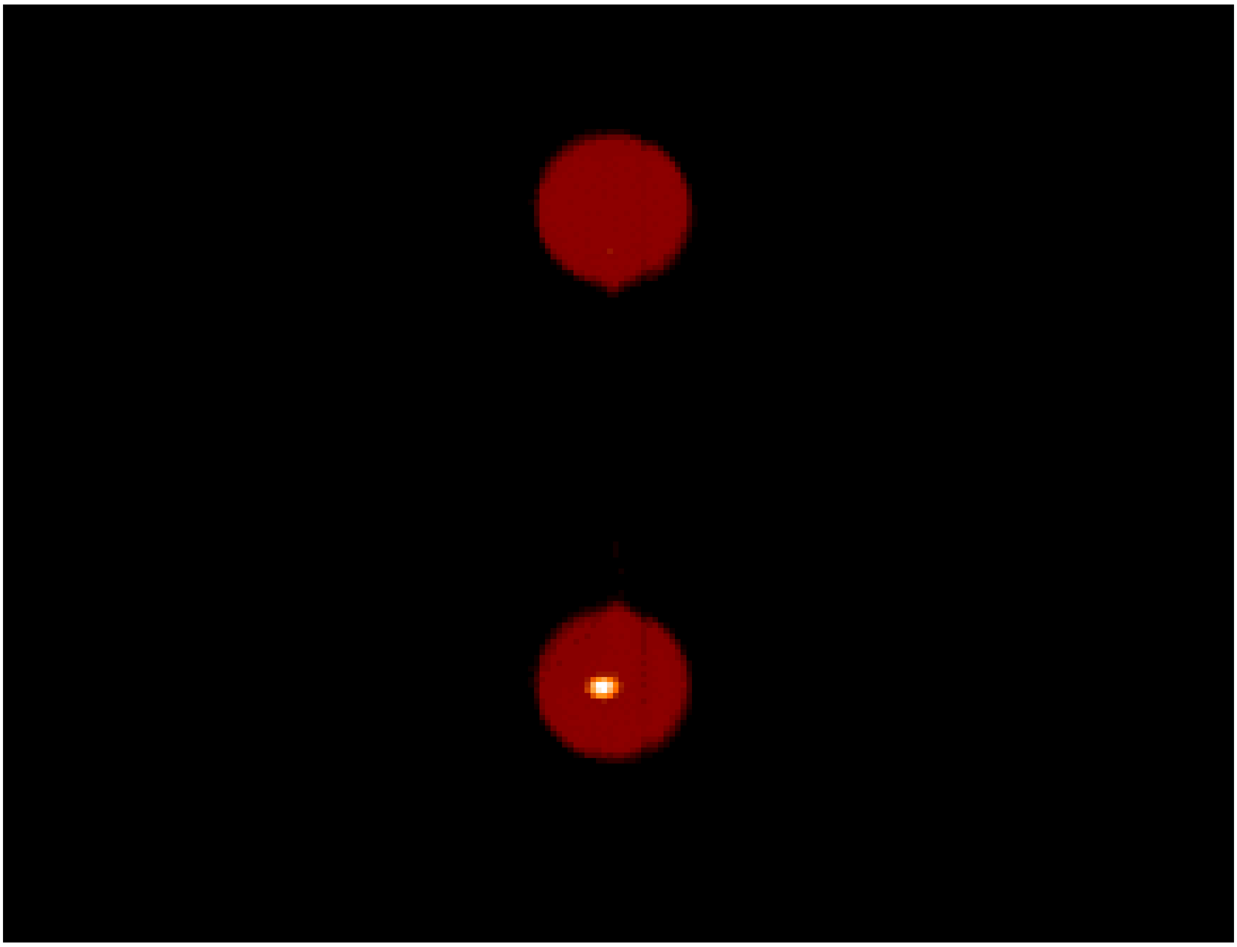

Fig 4.: MIDI-null obtained with a monochromatic light source. The picture shows the two interferometric output channels with destructive and constructive interference.

Beam quality

In addition to the distortions introduced by the atmosphere also the instrumental impact on the beam quality must be taken into account. The optical elements of MIDI are specified to a surface accuracy of less than 80 nm p-p. Even with spatial filtering the instrumental impact on the wavefront flatness will be in the order of about 10^{-2}. This is another limit for the nulling depth. To obtain the necessary quality of the beams, optical parts with higher accuracy or a correcting optical device might be essential.

MIDI test results

During the laboratory tests also the internal coherence loss of the MIDI instrument was measured by using a monochromatic light source. Fig. 4 shows the two interferometric output channels with constructive interference in one and destructive interference in the other channel. The result was equivalent to a nulling depth of about 10^{-1} . In case of broadband light this might be even less. For visibility measurements the coherence loss is not a big problem since it is the same for a calibrator star. For real nulling this is by far not enough and must be improved.

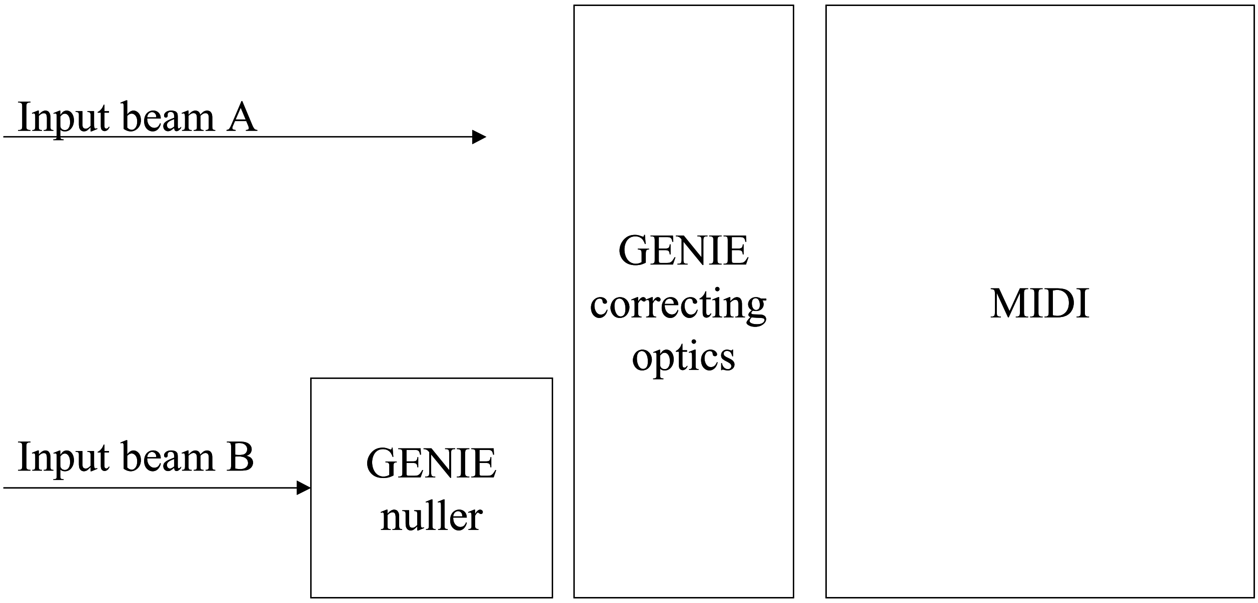

Fig. 5: Conceptional design of the MIDI nuller. MIDI is being augmented with an optical element(s) to correct for imperfect optics, and an optical element(s) to do the nulling.

CONCLUSIONS

A conceptional design of a MIDI nuller is presented in Fig. 5. and entails the current version of MIDI, augmented with an optical box in front of the MIDI optical table containing correcting optics (to improve the performance of MIDI, symmetry requirements) and an additional optical box for the nulling device (under cryogenic conditions). On the software side, additional modules would need to be developed which could include specific modulation schemes.

REFERENCES

[1] Leinert, Ch., Graser, U., Waters, L.B.F.M., Perrin, G., Lopez, B., Coudé du Foresto, V., Glazenborg-Kluttig, A.W., de Haas, J.C, Herbst, T.M., Jaffe, W., Lena, P.J., Lenzen, R., le Poole, R.S., Ligori, S., Mundt, R., Pel, J-W., Porro, I.L., and von der Luehe, O., "10-um interferometry on the VLTI with the MIDI instrument: a preview", *Proc. SPIE,* Vol. *4006*, pp. 43-53, "Interferometry in Optical Astronomy", P.J. Lena, A. Quirrenbach Eds., 2000

[2] Bakker, E.J., Leinert, Ch., Jaffe, W., Graser, U., de Jong, J., Chesneau, O., Meisner, J.M., Mathar, R., Neumann, U., Cotton, B., Percheron, I., Pel, J-W., Glazenborg-Kluttig, A.W., Waters, L.B.F.M., and Perrin, G., "MIDI scientific operation procedures", *Proc. SPIE*, Vol. 4838, 156, "Interferometry for Optical Astronomy II", 2002, W.A. Traub Ed.

[3] Ballester, P., Chavan, A.M., Cotton, B., Coudé du Foresto, V., Glindemann, A., Guirao, C., Jaffe, W., Kervella, P., Longinotti, A., Percheron, I., Peron, M., Duc, T-P, Pirenne, B., Quinn, P.J., Richichi, A., Schöller, M., Wicenec, A.J., Wilhelm, R., Wittkowski, M., and Zampieri, S., "Data flow system for the very large telescope interferometer", *Proc. SPIE,* Vol. *4477*, pp. 225-233, "Astronomical Data Analysis", J-Luc. Starck, F.D. Murtagh Eds., 2001

[4] Feldt, M., and Lopez, B., "SimVLTI: a simulation tool for VLTI instruments MIDI (and AMBER)", http://www.mpia-hd.mpg.de/MIDI/SIMVLTI/

[5] Quirrenbach, A., Coudé du Foresto, V., Daigne, G., Hofmann, K.H., Hofmann, R., Lattanzi, M., Osterbart, R., le Poole, R.S., Queloz, D., and Vakili, F., "PRIMA: study for a dual-beam instrument for the VLT Interferometer", *Proc. SPIE,* Vol. *3350*, pp. 807-817, "Astronomical Interferometry", R.D. Reasenberg Ed., 1998

[6] Gai, M., Corcione, L., Delage, L., Gardiol, D., Gennai, A., Lattanzi, M.G., Loreggia, D., Massone, G., Menardi, S., and Reynaud, F., "The FINITO fringe sensor for VLTI "*, ESO Proc.* "*Beyond Conventional Adaptive Optics"*, R. Ragazzoni, N. Hubin, S. Esposito eds., 2001

ACKNOWLEDGEMENTS

Funding for Leiden Observatory (**N**OVA **V**LTI **E**xpertise **C**enter NEVEC) to participate in the MIDI project has kindly been provided by NOVA, the Graduate Research School of Astronomy in the Netherlands.