MIDI - FIRST RESULTS FROM COMMISSIONING ON PARANAL

F. Przygodda[1], **O. Chesneau**[1], **Ch. Leinert**[1], **U. Graser**[1], **U. Neumann**[1], **R.J. Mathar**[1], **W. Jaffe**[2], **E. Bakker**[2], **J.A. de Jong**[2], **and S. Morel**[3]

[1]Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
[2]Leiden Observatory, P.O. Box 9513, 2300 RA Leiden, The Netherlands
[3]European Southern Observatory, Casilla 19001, Santiago 19, Chile

ABSTRACT

The mid-infrared spectral regime is of special interest for the detection of extra solar planets since the ratio of the planets flux to the flux of the host star is larger than at other wavelengths. Direct detection needs also high angular resolution in order to separate the planets signal from that of the star. High angular resolution at mid-infrared wavelengths – that is also the challenge met by MIDI – the MID-Infrared interferometric instrument – the first scientific instrument which is coming currently into regular operation at the ESO Very Large Telescope Interferometer on Paranal. This instrument is the the first interferometric instrument for the mid-infrared range, which combines the light of two 8m-class telescopes in a direct way. Therefore it provides high sensitivity together with the advantage of spectral analysis of the source in a range from 8 to 13 micron.
After MIDI demonstrated successfully its function by obtaining First Fringes in December 2002 it is now in the phase of commissioning. Here we want to inform about the current state of the commissioning and present some of the first results.

1. INTRODUCTION

The installation of MIDI in the interferometric laboratory of ESO's VLTI begun in November 2002 followed by a phase of alignment and verification. Several weeks later in early December the instrument was tested for the first time "on the sky". First, with the light collected by two 40cm siderostats, later by using the the two Unit Telescopes ANTU and MELIPAL. In the early morning hours of 15th of December the two 8-m telescopes were pointed towards the star Epsilon Carinae and the light were send via more than 30 mirrors to MIDI, where the instrument produced successfully "First Fringes". MIDI has been developed by a consortium lead by MPIA Heidelberg Germany (project scientist: Ch. Leinert, project manager: U. Graser) with contributions from NOVA/ASTRON (Dwingeloo, the Netherlands), Leiden Observatory, University of Amsterdam, Observatoire de Paris-Meudon, University Groningen and Kiepenheuer Institut für Sonnenphysik at Freiburg. The instrument is sensitive to light of mid-infrared wavelengths near 10 micron ("thermal infrared"). It provides rich opportunities to study a wide range of otherwise inaccessible, crucial astrophysical phenomena, e.g., the formation of planets in dusty disks around newborn stars.

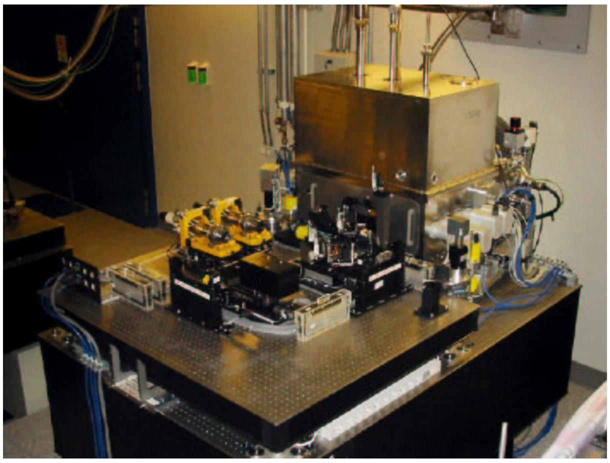

Figure 1. MIDI in the VLTI interferometric laboratory on Paranal. The instrument produced First Fringes in December 2002.

It is a great technical challenge to perform mid-infrared observations. This is first of all because the terrestrial atmosphere, the telescopes, the complicated optics system and the environment all emit infrared radiation with the maximum at around 10 micron, the wavelength where MIDI operates. Until now, no optical interferometer had to deal with such observing conditions. Other attempts to perform interferometry in the mid-infrared spectral regime where done in the style of radio interferometry (Bester et. al. 1990) providing only a small bandwidth and less sensitivity. Compared to that, MIDI is combining the light from the two telescopes

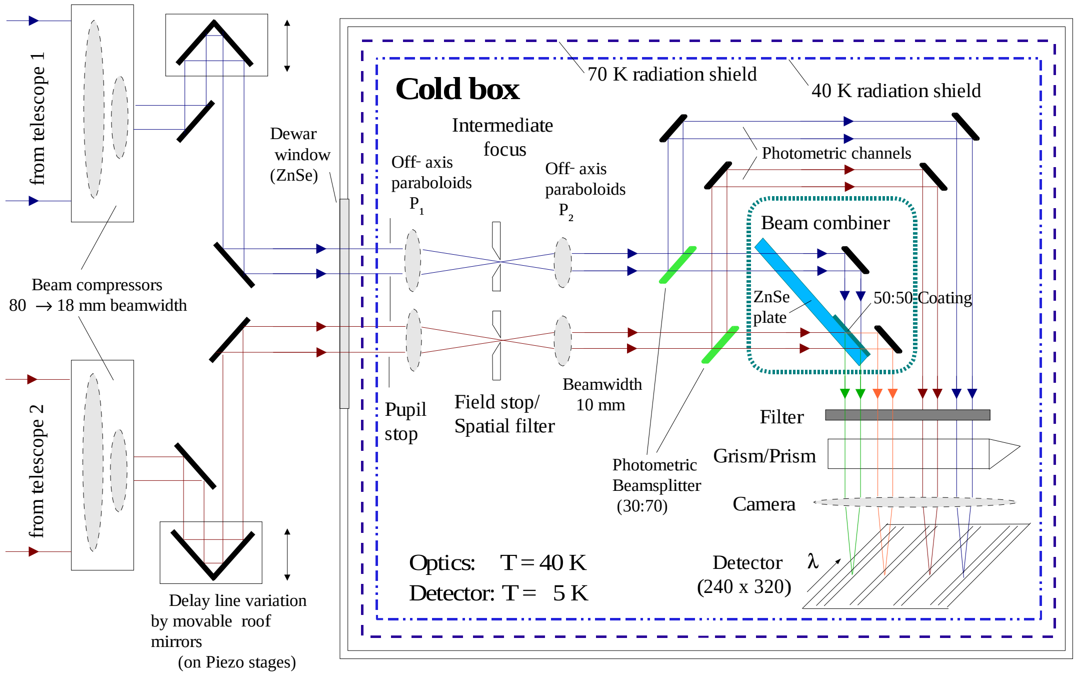

Figure 2. Schematic diagram of the instrument. For simplification the off-axis paraboloids P_1 and P_2 are displayed as lenses.

directly. This method offers the opportunity for broadband operation. The MIDI instrument is currently in a commissioning phase which will last the full year 2003. We will first briefly describe the MIDI instrument and its function. After this we focus on the scientific operation procedures for MIDI as they were in February 2003 followed by a presentation of some examples of obtained interferometric data.

2. BRIEF DESCRIPTION OF MIDI

The initial aim of MIDI is to combine the beams from 2 telescopes telescopes (which can be either 8.2m Unit Telescopes (UTs) or 1.8m Auxiliary Telescopes (ATs)), in the mid-infrared N-band with a spatial resolution of up to 10milli-arcseconds and a maximum spectral resolution of 230. (Leinert et. al. 2003) Interferometric observations at this spectral regime combine the difficulties of the relatively new interferometric techniques with the problems of overcoming the strong and highly variable thermal background which are typical of thermal infrared observations. Some functions like the modulation of the optical path difference can be done at room temperature, but beam combination and in particular the detection of the interferometric signal has to be done at cryogenic temperatures due to the ‘thermal wavelength domain. MIDI‘s cold optical bench, containing the main parts of the optics (Glazenborg-Kluttig et. al. 2003), is therefore mounted inside a cryostat, cooled by means of a closed cycle cooler to about 40K for the optics and down to 4K for the detector. Fig. 2 shows a schematic diagram of the instrument. 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”. Optionally a part of the light can be extracted before entering the beam combiner. This allows the photometric monitoring of the incoming beams for a better calibration of the interferometric signal. Up to the beam combiner, the system is purely reflective and all optical elements are in pairs, one set for each beam. After the beam combiner, the interferometric and photometric beams pass through the same refractive elements of the camera before they reach the detector. Filter and dispersive elements for spectral analysis of the signal can be inserted into the beam if desired. A special complication is the alignment of the MIDI cold optics, which is done at room temperature as the design of the cold bench is such that no adjustments are possible when the cryostat has been closed. The final result of the alignment however is not known until the cryostat has been closed and the instru-

Table 1. MIDI Templates tested in Feb. 2003

PRESET	sending telescopes to object
DEFAULT NOD	nodding to show background-subtracted field
DEFAULT CHOP	chopping to show background-subtracted field
ACQ NOD	centering of object in both beams, nodding
ACQ CHOP	centering of object in both beams, chopping
PHOTOMETRY	photometric measurement of the source
FRINGE SEARCH	fringe search by scanning optical path difference
FRINGE TRACK	this is the actual measuring mode

ment is operating at cryogenic temperatures.
The measurement of the visibility is realized by modulation of the optical path length in one beam by using one of the small piezo-driven 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 unavoidable internal coherence loss of the incoming beams the contrast is never 100% even for point sources and must be calibrated therefore. 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 down to 100 ms, the correction must be done on a shorter time scale. MIDI software is largely developed according to ESO standards with some deviations due to the special nature of MIDI (Bakker et. al. 2003). 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.

3. MIDI'S OBSERVING PROCEDURES

The scientific operation procedures is a set of pre-defined modes, which has been developed for the instrument and is supported by the consortium. The scientific operation modes for MIDI can be divided in two categories (Przygodda et. al. 2003): 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's rotation.
Currently the basic modes for the non-dispersed operation (Table 2) are tested during the first commissioning runs. The goal is to execute the different modes in an automatic way controlled by templates. For example the automatic pointing of the telescopes, the light injection to the tunnels and the adjustment of the delay lines have been tested successfully (template PRESET). MIDI is an N band interferometer, but in order to point the targets accurately, MIDI has also some imaging capabilities. Some pointing testings with nodding and chopping have been undertaken on a few stars during the first MIDI commissioning run of February 2003. The templates ACQ_NOD and ACQ_CHOP are designed to center the star on the right pixel in a fully automatic way. The template for the photometric measurement of the object (PHOTOMETRY) and the search for the fringe signal by a fine adjustment of the delay lines (FRINGE SEARCH) have demonstrated their functional efficiency. In the so-called self fringe tracking mode (FRINGE TRACK), MIDI's controlling system is able to compensate the OPD-variations introduced by the Earth's atmosphere and to keep the fringe packet stable.

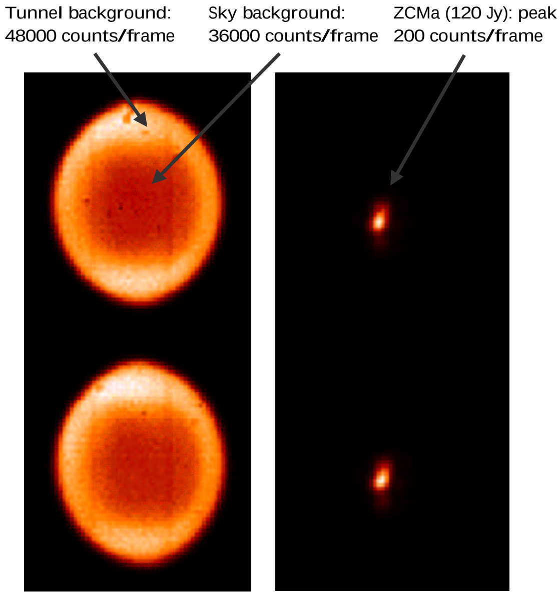

Figure 3. left: Raw images of the two interferometric output channels during an observation of Z CMa. The signal is dominated by background radiation from the sky (5-10 ° C) and the VLTI tunnel (17 ° C). right: The object becomes visible after subtraction of the background using the chopping procedure. (Exposure time: 1.5 ms/frame)

The figures 3 to 6 illustrate the interferometric observation of Z CMa using the 100m baseline between UT1 and UT3 during the night of Feb. 24th. While the main VLTI delay line is moving stepwise in a range of a few millimeters, MIDI's piezo-driven delay line is performing small additionally scans of 120 micron each. At the position where the optical path difference (OPD) between the two interferometric arms is almost zero, the correlated flux from the object becomes detectable in the subtraction of the two interferometric output channels . The amplitude of the fringe packet is proportional to the objects visibility but a careful calibration is necessary to obtain absolute values. Therefore the measurement of a reference star with known visibility has to be done in addition.

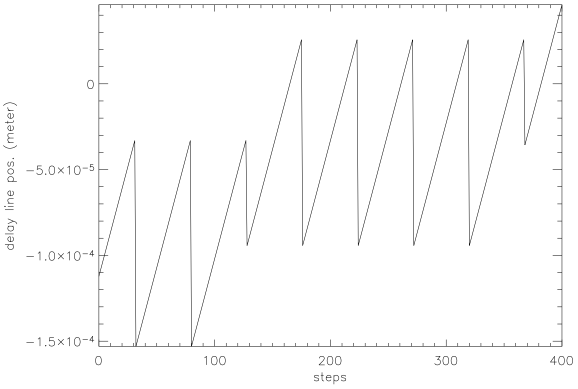

Figure 4. The OPD modulation during the procedure of fringe searching. The main VLTI delay line is moving stepwise while MIDI's small piezo driven delay line performs five ramps with an amplitude of 120 micron at each step. The procedure allows a fringe search in a range of more than 1 mm per minute.

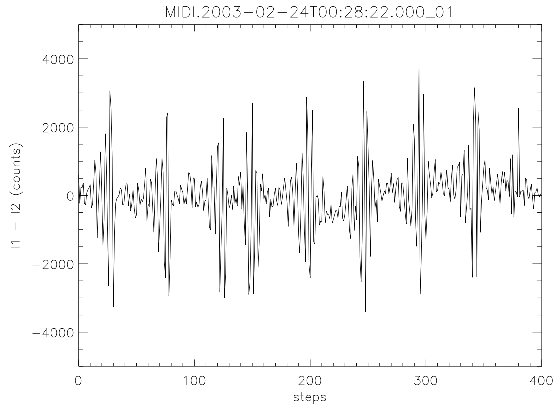

Figure 5. The interferometric signal obtained by subtraction of the two output channels near the zero-OPD position. The uncorrelated flux (background) is canceled while the correlated flux remains as a fringe packet. The corresponding delay line movement is shown in figure 4.

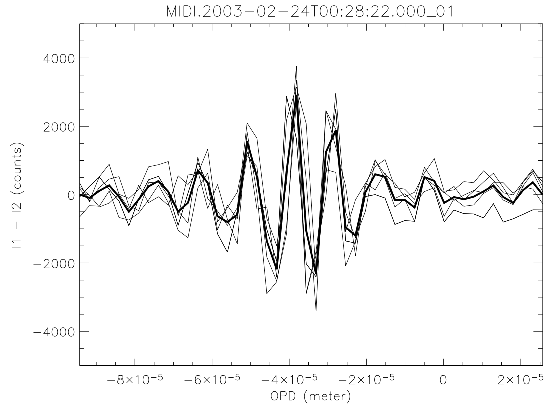

Figure 6. The superposition of five fringe packets and their average (thick line) plotted against the optical path difference (OPD). The width of the packets depends on the spectral bandwidths of the used filter (here full N band) while the amplitude is proportional to the objects visibility.

4. DISPERSED MODE

MIDI is the first interferometric instrument for the mid-infrared spectral regime which allows broad band operation in the N-band from 8 to 13 microns. For the spectral analysis of the signal one of ten different filters and two dispersive elements are available which can be inserted into the optical path. The prism provides a spectral resolution of $\Delta\lambda/\lambda$=25, the grism even a resolution of $\Delta\lambda/\lambda$=230. Figure 7 shows the spectral resolved flux of the two interferometric output channels in the dispersed mode (here by using the prism): the light of each channel is spread along the x-axis on the detector. This mode allows the high angular resolution analysis of the source at different wavelength within the N-band. A critical point is the strong and moreover time-variable influence of the Earth's atmosphere at mid-infrared wavelengths. The raw spectra in figure 8 show the typically dip around 9.5 micron caused by the ozone band. A careful calibration of the spectrum with a standard star is essential (procedures for reducing MIDI's spectral data are currently under development). Using the very accurate method of differential interferometry by comparing the correlated flux at different wavelengths at the same time, the detection of extrasolar planets with MIDI might be possible. For a detailed discussion of this method the reader is referred to the article "Direct Detection of Substellar Objects with MIDI" by P. Schuller et. al. in this volume.

5. OUTLOOK

During the first commissioning run fringe tracking was performed on a 9 Jansky source without any problems, but the limiting magnitude of the instrument in self fringe tracking mode will be not better than 1 Jansky. This limit is caused mainly due to the OPD variations introduced by the Earth's atmosphere. In fact MIDI is able to compensate the variations by recurrent measurements of the actual fringe position together with a corresponding adjustment of the delay lines, but therefor the correlated flux of the source must be strong enough to be detectable

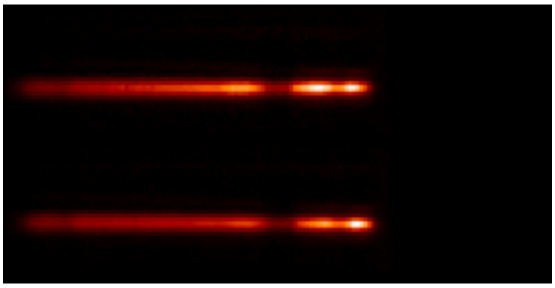

Figure 7. MIDIs two output channels in the dispersed mode using the prism which has a spectral resolution of $\Delta\lambda/\lambda$=25. The spectral range is 8 to 13 micron, shorter wavelengths are on the right side.

within the short time of the scans. The sensitivity can be increased by applying external fringe tracking. Once the fringe tracker *Fringe-tracking Instrument of NIce and TOrino (FINITO)* will be available later this year, fringe finding and tracking can be accomplished externally from MIDI which allows the coherent integration of the detector signal for faint and low visibility sources. This mode of operation will be referred to as "external fringe tracking mode". Together with the AO system MACAO, it is expected to increase the sensitivity by a factor of up to 100[1]. In a very limited number of cases this might be sensitive enough for the direct detection of such faint objects like extrasolar planets. MIDI's primary range of application can be found – next to other fields like for instance the study of AGNs – in the observation of young stellar objects and their circumstellar disks (Lopez et. al. 2000). Since disks are the place where planets form, MIDI will significantly extend our present knowledge of the the involved processes. MIDI's resolution will be in the order of 2 AU at 15O pc, the distance of the star formation region Taurus-Auriga. This match in spatial resolution will make it possible to carry out a direct study of the geometry of the inner parts of circumstellar disks, their geometry, chemical composition and evolution.

ACKNOWLEDGMENTS

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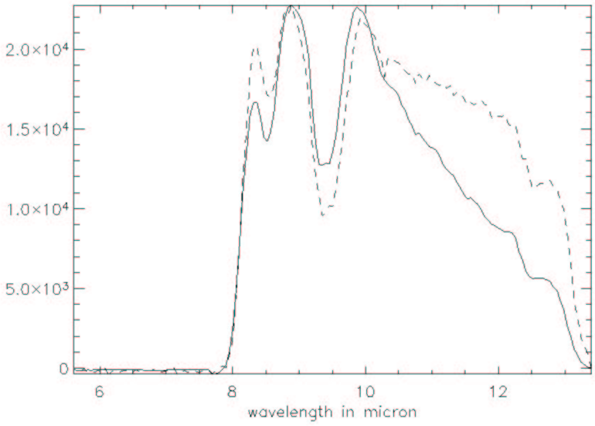

Figure 8. Uncalibrated spectrum of ZCMa (dotted line) and Eta Carinae (full line). The strong influence of the Earth's atmosphere can be seen at the dip around 9.5 micron which is introduced by the ozone band. A careful calibration with the spectrum of a standard star is necessary to avoid artifacts.

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[1] assuming an accumulated on source integration time of 1000s