INTERFEROMETRIC OBSERVATION AT MID-INFRARED WAVE-LENGTHS WITH MIDI

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Abstract. MIDI, the *MID*-Infrared *I*nterferometric Instrument for ESO's Very Large Telescope Interferometer (VLTI), will be the first instrument for combining mid-infrared light directly in order to obtain angular resolution up to 10 mas (assuming a 200 m baseline) in a wavelength range from 8 to 13 μm. Currently in the phase of commissioning at Paranal, the start of its scientific operation is expected for summer 2003. Direct interferometry at thermal infrared wavelengths demands special requirements on the instrument and also on the procedures of preparation of data reduction. Hereafter MIDI's different observing modes are described and an example for an interferometric observation is given.

Keywords: VLTI, MIDI, interferometry, interferometric observation, infrared observation, mid-infrared, thermal infrared

1. Introduction

1.1. Interferometry at thermal-infrared wavelengths

Observing at mid-infrared wavelengths has its special attributes due to the characteristics of the earth's atmosphere. Compared to the optical and the near-infrared regime, the size of turbulence cells and also the time scale of their stability is larger. The Fried parameter r_0, which is connected to the effective size of the cells, reaches approximately 5 m at an observing wavelength of 10 micron. The atmospheric coherence time, within the atmosphere can be considered as stable, averages to about 100 ms. These numbers give the impression that observing at mid-infrared wavelengths is an easy undertaking, but one property was not mentioned yet: the extremely high and temporally changing background radiation of the sky. Compared with the signal of, for instance, a N = 0 mag object, the flux per arcsec from the sky is about 10 times larger. The usual way to overcome this problem is the application of a technique called 'chopping and nodding'. 'Chopping' means the quick tilting of the secondary (or another convenient) mirror with a frequency of several Hz while images are taken alternately at the two orientations. After the subtraction of the images, the sky background is mostly canceled and mainly the object's signal resides. To cancel also the small but non-avoidable influence of

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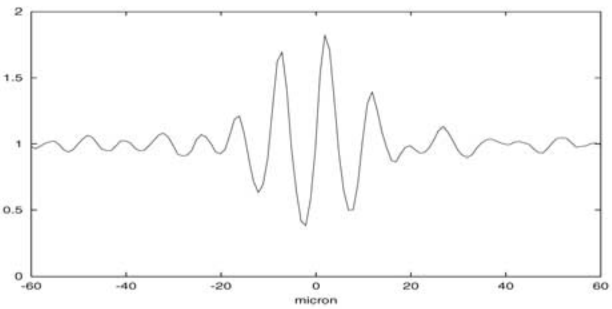

Figure 1. Fringe packet obtained during an OPD scan of 140 micron. Plotted is the normalized flux of the interferometric output channel (real MIDI test data).

the telescope on the background flux, which is connected to the orientation of the chopping mirror, the whole telescope can be pointed to an off-source position. This so-called ‘nodding’ of the telescope, together with a repetition of the chopping-procedure at the new position, allows the nearly complete cancellation of the disturbing background. Before this technique will be explained more detailed in the context of MIDI we start with a general description of the visibility measurement.

1.2. Fringes and visibility-measurement

The main objective of the MIDI instrument (Ch. Leinert et al., 2000) is the coherent combination of the two input beams in order to achieve object information with high angular resolution. The combination takes place in MIDI’s beam combining unit where the light coming from the two telescopes interferes at a 50%/50% beam-splitter plate. In this type of interferometer, also known as *on-axis pupil plane interferometer*, the result of the interference is imaged after the combination in form of two interferometric output channels on the detector. If one of the interferometric channels shows destructive interference of the light, the other shows constructive, and the other way round. By introducing an OPD (= Optical Path Difference) between the two input beams, which is larger than the coherence length of the observed light, the interference pattern disappears. Therefore, a scan of the OPD around its zero position results in the measurement of a ‘fringe packet’ (see Figure 1). The strength of the modulation of the signal, the so-called ‘fringe contrast’, depends on the object’s visibility function and the baseline used. The fringe contrast is the observable which contains the object information with high algular resolution.

Two different methods for an accurate measurement of the fringe contrast are described in the following:

– Fourier-Method: Monitoring the flux of the interferometric output channels during a long OPD-scan across the zero-position results, like described above,

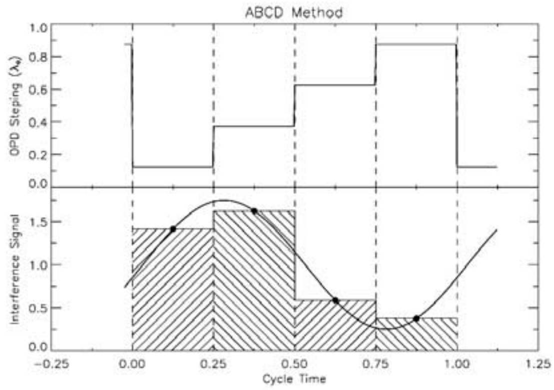

Figure 2. Measuring the fringe contrast by scanning the fringe in four steps. *upper graph:* OPD steps, *lower graph:* measurement of the flux at four points.

in the measurement of a fringe packet. The Fourier transform of this dataset shows a broadened peak at the frequency of the fringe modulation. The area of the peak is proportional to the object visibility. This method is insensitive to OPD shifts (introduced for instance, by the atmosphere or the hardware) as long the whole fringe packet in within the range of the scan.

– ABCD-Method: This faster method just needs the flux in the interferometric output channels at four different points. For this, MIDI's piezo-driven internal delay line performs four equidistant steps, with a distance of $\pi/2$ in terms of the measured wavelength (see Figure 2). This method needs an exact fringe tracking to avoid phase shifts within the measurement time of the four values. Also, it must be ensured that the measurement is executed at the center of the fringe packet. The object visibility V is proportional to $\sqrt{(A-C)^2+(B-D)^2}$, with the flux A,B,C,D at the four steps.

Since in both methods the non-avoidable contrast loss due to instrumental and atmospheric effects is not determinable, in *any* case the measurement of a reference object with known visibility is necessary for calibration.

2. MIDI's Observation Modes

2.1. Non-dispersed modes

As a mid-infrared instrument, MIDI also uses the chopping and nodding procedure. A special difficulty is the quick finding and tracking of the fringes during the on-source position. This process needs a complex and fast control system for the MIDI instrument and the whole VLTI infrastructure including the two telescopes (S. Hippler et al., 2000). An easier way to deal with the disturbing background is MIDI's so-called 'virtual chopping'. Here, the background flux at the objects

Figure 3. Detector images taken in two different observing modes: 'High Sens Mode' (left) with only the two interferometric output channels and 'Photometric Mode' (right) with two additional photometric channels. Every channel shows an image of the triple pinhole used here. Slits have the same orientation as the triple pinholes.

position on the sky is derived from the flux at two near off-source positions by using an interpolating routine. For this method, either a long slit or a special set of pinholes can be inserted in MIDI's intermediate focus. These pinholes or 'field stops' consist of three single holes. The source is put to the center one, while the other two are dedicated to the background measurement. Figure 3 shows detector images taken with this kind of field stop. Each of the interferometer output channels appears as three single spots.

To increase the accuracy of the interferometric measurement (see below), MIDI has also the option to image two photometric channels. This 'Photometric Mode' enables the monitoring of the flux in the input beams before the interference takes place. For this, 30% of the light is extracted and bypasses the beam combining unit. Since the fringe amplitude depends naturally also on the flux ratio of the two input beams, the 'true' visibility can be calculated by taking into account the information from the photometric beams. Here, in difference to the more sensitive 'High Sens Mode' without photometric beams, the precision of the fringe contrast measurement is higher. (for a detailed description see also: V. Coudé du Foresto et al., 1997)

2.2. Dispersed modes

An unique feature of MIDI is the option of interferometric broad-band observations in a spectral range from 8 to 13 micron. For this, two dispersive elements can be inserted in the optical path. A prism allows observations with a spectral resolution of about R=25, a higher resolution of R=230 can be obtained by inserting the grism. By using these elements the images of all output channels are dispersed along the x-axis on the detector (see Figure 4). These modes, which would be used with a long slit or a triple pinhole, allow the measurement and comparison of the fringe contrast (see next section) at different wavelengths at the same time. This technique is also known as *differential interferometry*.

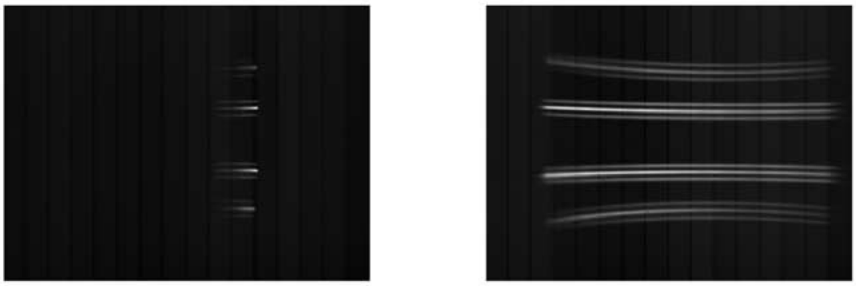

Figure 4. Dispersed modes with the prism (left) or the grism (right). Interferometric and photometric channels are spread along the x-axis.

2.3. PERFORMANCE OF MIDI

In the following, an overview of MIDI's expected performance is given. Since the instrument in not yet tested together with the VLTI infrastructure, the values may differ in reality.

Visibility accuracy: $\Delta V/V = 5$ %
(problem is mainly calibration, not instrument)
Limiting magnitude: (broad band operation or with prism)
– with UTs: N $\approx$ 3–4 mag (1–2.5 Jy)
– with ATs: N $\approx$ 0.8 mag (20–50 Jy)
– with dispersion by grism : 1–1.5 mag less sensitive than undispersed
– with external Fringe Tracking: up to 5 mag more sensitive

3. Example: Observation of Z CMa

Even more than with other instruments, the observation with an interferometer needs an accurate preparation. Useful tools for that are simulation programs like ASPRO (by Laboratoire d'Astrophysique de Grenoble), SIMVLTI (by MPIA Heidelberg) or ESO's VLTI visibility calculator. Those software packages make it possible to get an idea of the expected visibility values for given parameter setups. For a better understanding, the preparation of an observation of Z CMa is given as an example hereafter.

Z CMa is a FU Orionis type star with an IR companion at a separation of 0.1 arcsec (known from speckle observations, C. Koresko et al., 1991). An infrared excess indicates the existence of dust in the system. Observations with MIDI would clarify the location of the dust: is there a circumbinary or a circumstellar distribution of the dust? The first step is to create a model of the system with the known (and assumed) parameters (Table 3). Figure 5 shows the output of SIMVLTI for the chosen parameters. The upper right graph shows the 2-dimensional visibility function in the spatial frequency domain (also known as uv-plane) which is calculated by a Fourier

TABLE I
Model parameter for Z Cma

total brightness	N = -1.28 mag
separation	0.1 arcsec
position angle	120 deg
two circumstellar Gaussian disks assumed	diameter 10 mas (FWHM)
flux ratio	1:2
investigated VLTI baseline setups	UT1–UT2 (56m), UT1–UT3 (103m)
observing time	5 hours

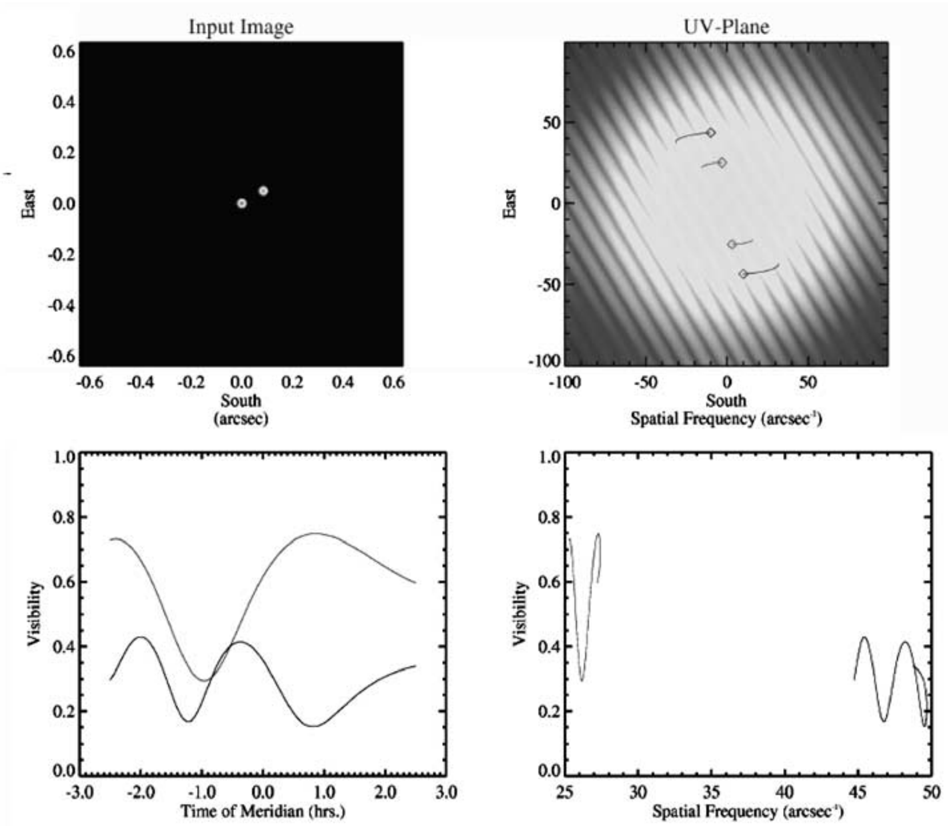

Figure 5. Screen-shots from SimVLTI. *Upper left:* intensity distribution on the sky, *upper right:* 2D object visibility function and superposed uv-tracks, *lower left:* expected visibility vs. observing time (for the two baselines), *lower right:* same, but visibility vs. spatial frequency

transform of the given intensity distribution. The intensity distribution of the model can be understood as a convolution of a Gaussian disk with two delta functions with a distance of the separation of the binary. Since a convolution of two functions becomes a multiplication of their Fourier transforms in the frequency domain, we find there a sinusoidal pattern (resulting from the delta peaks) multiplicated with another Gauss function (resulting from the Gaussian disk).

The program calculates also the so-called *uv-tracks*. These are tracks in the frequency domain, where the object visibility function can be measured with the selected baseline configuration during the observation time. Responsible for the track's shape is the projected length and orientation of the baseline with respect to the object which changes with time because of the earth's rotation. With a cleverly chosen configuration it is possible to detect the sinusoidal pattern as well as the Gaussian decrease of the pattern to higher frequencies.

The parameters of the sinusoidal pattern are connected to the separation, position angle and flux ratio of the binary. Note, that they will not be measurable, if the projected baseline is perpendicular to the position angle of the binary. The measurement is a verification of the binary separation but gives also the flux ratio at 10 μm.

Obtaining the parameters of the Gaussian shape by measuring the visibility function at lower and higher spartial frequencies (using UT2-UT3 and UT1-UT3) allows to determine the size of the disks. A larger (i.e. circumbinary) disk would result in a smaller FWHM of the Gaussian part in the visibility function. Therefore, a interferometric measurement with the chosen parameters can give an answer to the question of the size and location of the disks.

The basic message of this example is that the baseline configuration must be adapted to the object parameters in a way that the obtained data is able to give answers to astronomical questions. Therefore a proper preparation of the observing run is essential.

References

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ASPRO:
`http://www-laog.obs.ujf-grenoble.fr/~jmmc/download/aspro/`
SimVLTI:
`http://www.mpia-hd.mpg.de/MIDI/SIMVLTI/SimVLTIdownload.html`
VLTI Visibility Calculator:
`http://www.eso.org/observing/etc/preview.html`