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MIDI, THE 10 μM INTERFEROMETER OF THE VLT

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Abstract. We report in this paper on the current status of the mid-infrared beam combiner of the VLTI: MIDI. We explain the interest of VLTI for this range of wavelentghs and give an overview of the main characteristics of MIDI and present its scientific targets.

1 Introduction

The interferometric array of the Very Large Telescope (VLTI) on top of mount Paranal in Chile has entered its operational phase in the first half of 2001 when it acquired its very first fringes with VINCI (Glindemann 2000). MIDI, the Mid-InfrareD Interferometer, will be the first scientific instrument available on VLTI. It will operate in the astronomical N band between 7 and 13 μm. It will pioneer direct interferometry in this range of wavelengths under conditions of high background, high read noise and with advanced diffraction beam perturbation.
Ground based optical-infrared interferometry has provided stellar physics with unique results but these have been mostly limited to wavelengths smaller than 2.5 μm. A single instrument exists for the very beginning of the thermal infrared range in the L band (centered on 3.75 μm) where background noise is not yet dominating for short exposure interferometric observations (Mennesson *et al.* 1999). Only two long baseline interferometers have been built in the 10 μm range and only a few late-type stars with dusty environments have been observed in the thermal infrared. MIDI will increase the number of stellar sources in this wavelength range as well as the type of sources. In particular, extragalactic sources

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will become within possibilities.
We review in this paper the design of MIDI and we present the main operating modes. We describe the issue of background subtraction as this will be one of the specifics of MIDI. The outline of its astrophysical program is presented and its current status is given. We first explain why the VLTI is well suited for mid-infrared interferometry.
MIDI was previously presented in several conferences with its then current status. (Leinert & Graser 1998; Perrin *et al.* 2000; Leinert *et al.* 2000).

2 Rationale for $10\,\mu$m interferometry on the VLTI

The sensitivity of optical and near-infrared interferometers is essentially limited by turbulence. Turbulence destroys the coherence of the beams unless the entrance pupils diameters are stopped down to a Fried diameter. This severely limits the sensitivity. Even under these conditions, the differential piston effect of turbulence causes a random drift of the fringes. The fringes need to be acquired in a differential piston coherence time of a few tens of milliseconds at most, thus reducing again the sensitivity of interferometers. These sensitivity limitations are greatly reduced by the use of adaptive optics and fringe tracking systems which stabilize the phase in the pupil and the differential piston allowing the use of large pupils and making relatively long exposures possible. These limitations still hold in the mid-infrared but are relaxed. The Fried diameter in good astronomical sites is of a few meters (6 meters at Paranal at a wavelength of $10\,\mu$m) and the coherence time of the differential piston is on the order of 100 ms (it scales as $\lambda^{6/5}$ where λ is the wavelength). Besides, with an outer scale of turbulence of about 20 meters, the rms piston should be of 2 wavelengths at $10\,\mu$m making fringe tracking relatively easy. The mid-infrared range is therefore very favorable for interferometry from this point on view.
The resolution of an interferometer being proportional to the reciprocal of the wavelength, long baselines are required to reach resolutions of a few tens of milliarcsecond feasible with single telescopes at shorter wavelengths. VLTI offers four 8 meter telescopes with a maximum baseline of 130 meters, hence a resolution of 16 mas at $10\,\mu$m. On bright sources longer baselines up to 200 meters will be within range with the ATs providing a resolution of 10 mas. The resolution achievable will allow to study objects in the mid-infrared with resolutions already available at shorter wavelengths. Although the emitters in this range of wavelengths are usually characterized by larger spatial scales than at shorter wavelengths (dust around stars for example) thus *a priori* requiring less resolution, it will be possible to bridge the gap between smaller scales studied at shorter wavelengths and larger scales studied in the thermal regime.
$10\,\mu$m emitters spanning larger scales regions, the spatial structure of objects may be rather complex. With four UTs VLTI will provide six baselines which, thanks to Earth rotation, will produce a good coverage of the (u,v) plane for all the objects within the sensitivity limits of MIDI. This coverage will be extended with the use of ATs for bright sources. This potential is unique.

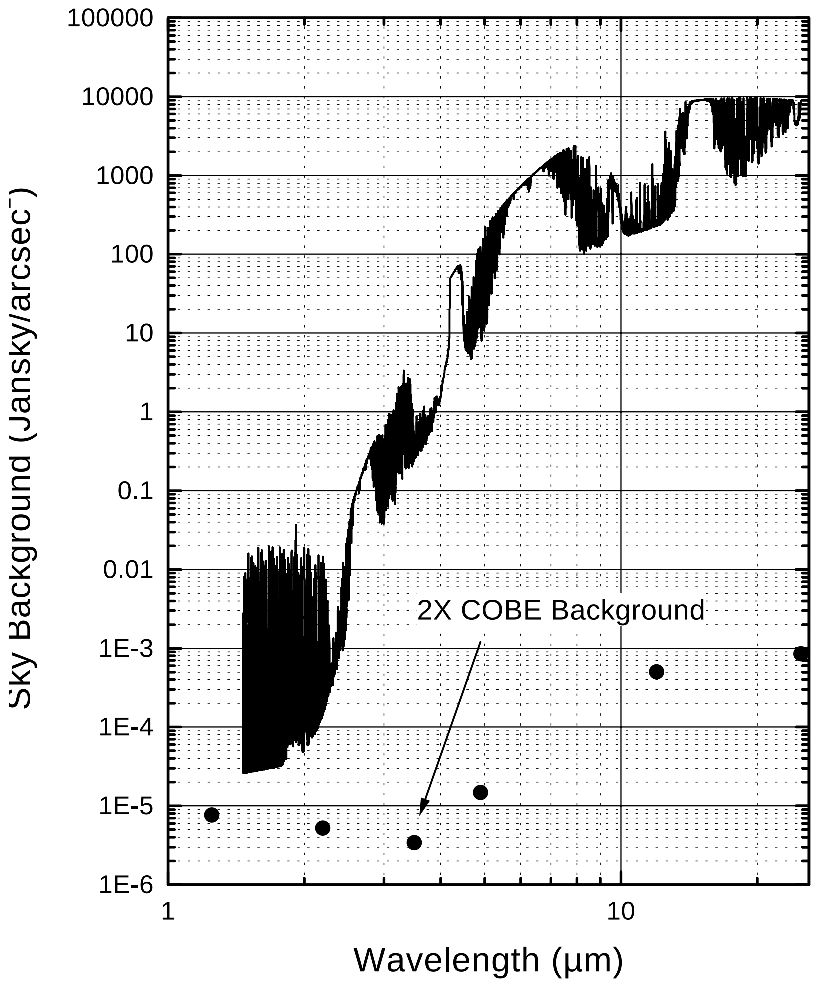


Fig. 1. Simulated combination of sky and telescope radiation above the Mauna Kea observatory from Gillett & Mountain (1998). The telescope temperature is 273 K and its emissivity is 3%. The contribution of the telescope to the total background is only one third at 10 μm.

Mid-infrared observations suffer from a low sensitivity. The main reason is the emission of radiation by the background (sky+instrument). This will be addressed in more details in the next section. In single-mode instruments, the flux received from a point source is contained in an Airy disk and is proportional to the squared diameter of the aperture. The flux collected from the background in an Airy disk is independent of the telescope size and proportional to the coherent beam étendue λ^2. When limited by the background radiation, the sensitivity is therefore proportional to the telescope pupil area, hence the gain in sensitivity brought by UTs on VLTI.

For the above reasons, very few experiments for $10\,\mu$m interferometry exist or have been tried. The only two, with diluted apertures, are the Infrared Spatial Interferometer (ISI) of the University of Berkeley (Danchi*et al.* 1990) and SOIRDÉTÉ of Observatoire de la Côte d'Azur (Rabbia *et al.* 1990). ISI is using heterodyne detection which makes it a particular IR interferometer (its operating mode is close to that of a radio interferometer) and limits its sensitivity. SOIRDÉTÉ was a wide band interferometer. Although it could detect fringes on stellar sources, visibilities could not be calibrated because of the fluctuating thermal background. SOIRDÉTÉ is not operated anymore. In these two cases, the relatively small telescope apertures forbid the access to astrophysical objects with positive N band magnitudes. Fringes can be calibrated on ISI down to magnitude -1.8. The large apertures of the VLTI will therefore offer a higher sensitivity and an unprecedented resolution (16 mas at $10\,\mu$m with the unit 8 m telescopes and 10 mas with the auxilliary 1.8 m telescopes). MIDI will as a consequence give access to new fields in high angular resolution astronomy in the thermal infrared wavelength range.

3 The background issue in the mid-infrared

In the 7-13 μm window, both the sky and the instrument emit radiation the power of which is much larger than the power of the radiation collected for most astronomical sources. The power of the sky background simulated at Mauna Kea (Gillett & Mountain 1998) is plotted on Figure (1). The contribution of the telescope at $10\,\mu$m is included but only represents one third of the total flux. It can be considered that this curve is a good estimate of the sky background. The background is 5 orders of magnitude brighter in this window than in near infrared regions up to $2.4\,\mu$m. The sky background is computed from the emission of water vapor in the atmosphere. The altitude of VLTI being lower than the Mauna Kea summit, the column density of water vapor will be higher and the extra low altitude layers will have larger temperatures. The background will therefore be more important than what can be derived from this plot. Techniques to observe despite this high level of background are well known and are all the more efficient as the telescopes are optimized for the thermal infrared. Unfortunately, the number of mirrors required to guide the beams in an interferometer is quite large and the emissivity of the instrument is not negligible. On VLTI, the train of optics is designed to have a transmission of 40% and the transmission of MIDI is 60%. The total flux received by MIDI per Airy disk at $10\,\mu$m is assessed at a level of 500 Jy corresponding to a magnitude of -2.7 in the N band for an 8 m telescope. The sky is therefore only contributing a small fraction to the total background. The observations with MIDI will differ from classical ground based observations in the mid-infrared where the instrument as a much smaller contribution to the

Background (photons)	Equivalent N on sky	Background (photo-e$^-$)	Equivalent N detected by MIDI
1.5×10^{10}	-2.7	6×10^9	-4.2
1.5×10^9	-0.2	6×10^8	-1.7
1.5×10^8	1.7	6×10^7	0.2
1.5×10^7	4.2	6×10^6	2.7
1.2×10^5	10	8×10^4	7.9

Table 1. Magnitude of the thermal background. The first row is the total amount of background collected by MIDI in 100 ms. The next rows are 10%, 1% and 0.1% of this level. The last row is the amount of photon noise. The first column is in photons. The second column is the equivalent magnitude on the sky assuming a transmission and quantum efficiency of 100%. The third column is in photo-events detected. The fourth column is the equivalent magnitude with the transmission of MIDI+VLTI and detector quantum efficiency.

background. Besides, some of the optics are in motion (delay lines) or are rotating (Coudé trains) during the observations. The influence of background on the sensitivity of MIDI will therefore be threefold:

1. background photon noise
2. detector saturation
3. background fluctuations

Each item is examined in more details in the following paragraphs.

Background photon noise The number of photons from the background in a coherent beam étendue is independent from the diameter of the telescope. With a transmission of VLTI of 40% and a transmission of MIDI of 60%, the number of photons per Airy disk collected from the background in the full N band ($\Delta\lambda = 4\,\mu$m) in 100 ms is equal to 1.5×10^{10}photons. The coresponding rms photon noise is 1.2×10^5 photons. The same power is delivered by a 10 magnitude star with 8 m telescopes for a quantum efficiency and a transmission of 100%. Taking into account transmission and detector quantum efficiency, the photon noise amounts to 8×10^4 corresponding to a 7.9 magnitude star. It is to be noticed that transmission in the infrared is twice critical. First, it causes source photon losses. Second, the lower the transmission the higher the train of optics emissivity and therefore the amount of background. With such a high level of background photon noise, detection is not limited by dark current or read out noise but primarily by the background.

Dectector saturation Modern detectors have a quantum well depth of 10^7 photo-electrons. For integration of a few tens of milliseconds, the background signal saturates the detector. The beams need to be spread over a few hundred pixels to allow integration times of at least a few tens of milliseconds. This operation can be achieved at no extra cost in noise if the background photon noise per pixel remains higher than the read out noise. With a read out noise of 1000 electrons the background noise is still the dominating noise if pixels are close to be saturated. If more dispersion is introduced, read out noise will become non negligible and will decrease the sensitivity. The background is therefore twice a source of noise. It has its own photon noise and because signal has to be spread over a large number of pixels, read out noise is not totally negligible.

Background fluctuations The statistical fluctuations of the background are not the only fluctuations to be feared. The temporal fluctuations may prevent from detecting the fringes if their energy is larger. Two sources contribute to the total background: the atmosphere and the instrument. Supposing that most of the sky background is due to water vapor in the $10\,\mu$m window it is possible to estimate the amount of spatial and temporal fluctuations. These may be produced by local fluctuations of temperature. This problem is very similar to atmospheric phase turbulence and a model of turbulent background may be adopted. The structure of non-convecting clouds is a good example of a Kolmogorov-type structure. Assuming that the fluctuations are generated by the drifting water vapor layers in front of the observatory at a characteristic speed $V = 15\,$m/s, with an outer scale $L_0 = 20\,$m the power spectral density of the temporal fluctuations can be simulated from a von Karman spectrum:

$$W_{back}(\nu) \propto {L_0}^{-8/3}\left[\frac{\nu^2}{V^2} + \frac{1}{L_0^2}\right]^{-4/3} \tag{3.1}$$

The proportionality coefficient is unfortunately unknown as no such measurement has never been performed. Yet, it is interesting to compute the amount of relative fluctuation above a certain cut-off frequency from this model in the worst case scenario. The power spectral density is rapidly decreasing with frequency. Most of the energy is therefore at lowest frequencies. Above 5 Hz for example, the amount of fluctuation is only 2% of the total fluctuation. It drops to 0.6% above 10 Hz. The worst scenario would be that the sky background varies from zero to its mean value around 30-100 Jy (the upper value being a pessimistic estimate of the background level at Paranal derived from that at Mauna Kea). In, this worst case the sky fluctuation amplitude is at most a fraction of a Jansky above 10 Hz, equivalent to a magnitude fainter than 4. Robberto & Herbst (1998) have shown that sampling the sky background at 5 Hz is sufficient to remove most of the background fluctuation noise on UKIRT.

The other potential source of background fluctuation may be the train of optics in front of MIDI. The moving mirrors may modulate both the instrumental and the sky background. Because the instrumental background is much larger, its modulation would strongly impact the sensitivity of MIDI. The corresponding magnitudes as seen by MIDI for several magnitudes of background modulations are listed in Table 1. It is clear that even small relative fluctuations of 1% would have a strong

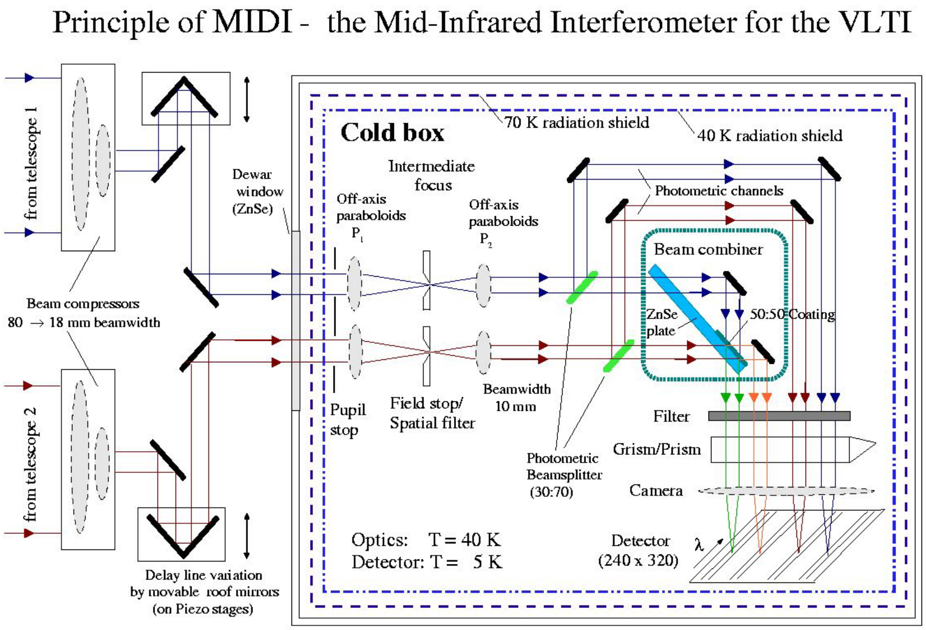


Fig. 2. The concept of MIDI

impact. Yet, since the spectral characteristics of these potential fluctuations are not known, the total fluctuations integrated over the all temporal spectrum are given. The effect would be less if filtered in the band pass of the fringes and one should expect lower values in practice. VLTI has been carefuly designed to limit the effects of background. The delay lines are equipped with variable curvature mirrors which permanently image the pupils at a fixed position at the entrance of the MIDI cryostat thus limiting the variations of stray lights. The first results obtained with VINCI on the UTs have shown that the Coudé trains are very stable and do not generate an important modulation.

As expected, beyond the instrument design and realization, background fluctuations will be a major challenge for MIDI. They may limit the sensitivity more than the background photon noise will. The quality of the VLTI design will limit their impact. But strategies have to be developped to counter their effects.

4 Concept and design

4.1 Guidelines

As the very small number of working experiments show (only one as of today), 10 μm interferometry is still challenging. As discussed above, the main challenge

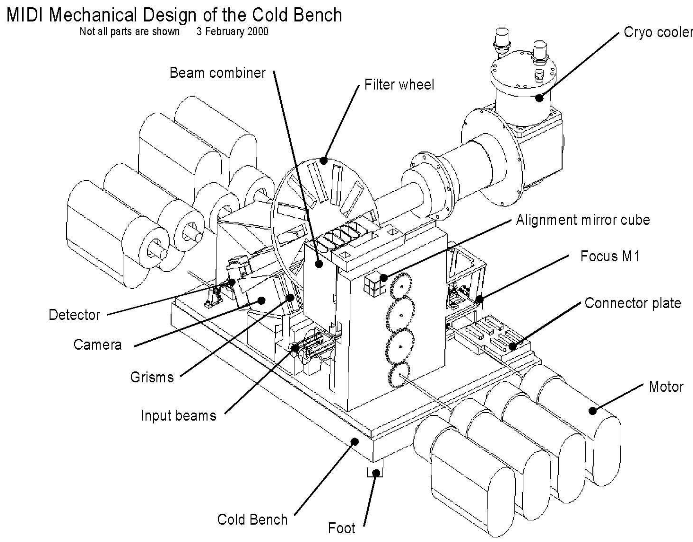


Fig. 3. The design of the MIDI cryostat. The cold bench size is 580 x 420 mm

is the large thermal background. In order to reduce it, most of the optics have to be kept at cryogenic temperatures. This imposes the instrument design to be as compact as possible. This leads to making the choice of a simple instrument with simple functions.

Several critical choices have been made. In order to reduce the number of optics, the choice was to limit the number of beams to a minimum of two beams thus forbiding the possibility to measure closure phases with MIDI although VLTI offers more than two telescopes. The space enveloppe for a three or four beam combination system would have been much larger making cryogenic operation more difficult. In any case, phase measurements will be posible in the future by phase referencing with the PRIMA (Phase Reference Imaging and Microarcsec Astrometry) instrument.
Two possible schemes for the beam combination were possible: a coaxial beam combiner or a multiaxial beam combiner. The multiaxial solution allows to use the same optics to perform the beam overlap in a focal plane and the beam focusing on the detector. Yet, spatial fluctuations of mid-infrared detectors being a potential risk jeopardizing the quality of the data, it has been decided to choose a coaxial scheme for the combination as all the flux of the combined beams in one interferometric channel can be detected on a single pixel. A consequence of this choice is that an optical path difference scanning element is required in MIDI to generate the fringe pattern.
Most of the instrument being cooled, the required degrees of freedom of the optics

need to be motorized. But motors dissipate energy which damage the cryogenic capacity and increase the background. For this reason, the design has to be compatible with a small number of motors for alignments. Most motors in MIDI are used to change filters and lenses. Only two optics adjustments are possible. The experiment has to be aligned at room temperature and the quality of the alignment must be kept after cooling.
MIDI will feature a dispersive element to spread the signal over a sufficient number of pixels to avoid saturation of the detector by the background. In order to reduce the background and improve the quality of the calibration of the visibilities, beams will be spatially filtered to select a coherent beam étendue.

These are the guidelines of the MIDI instrument.

4.2 The MIDI concept

The MIDI concept is shown in Figure 2. Except for the delay lines used for optical path difference modulation, all the optics of MIDI in the VLTI recombination laboratory will be cooled down to 40 K. MIDI therefore has warm optics and cold optics. The cold box is a dewar whose first radiation shield is cooled by liquid nitrogen. The experiment inside the second radiation shiel is cooled by a two-stage closed-cycle cooler as no liquid helium ca be used at Paranal. All components are forced to a temperature of 40 K except for the detector which is kept at a temperature of 5 K. The detector is a 320x240 focal plane array from Raytheon. The beams are introduced in the dewar by two windows. Two pupil stops block stray lights after the windows. The pupil locations are stabilized by varying the curvature of the secondary mirrors of the VLTI delay lines during motion. The beams are focused and spatially filtered in a focal plane. Several filters can be choosed whose size vary from a single Airy disk (single-mode operating mode with pinholes or fibers) up to a full VLTI field of 2 arcsec which can be obtained with a circular hole or with a slit. The beams are made afocal with parabolas and feed the beam combiner. Photometric beam splitters which can be moved out of the beams can sample 30% of the beams for the photometric calibration required in single-mode operation to achieve visibility accuracies of 1%. The two main beams are then overlapped on the beam splitter beam combiner producing two complementary interferometric channels. The beam splitter is a ZnSe plate with 50% transmission-reflection coefficients. The beams (four if the photometric beam splitter is in the beam, two ortherwise) go through a filter wheel and dispersive elements and are eventually focused on the detector. MIDI will have two dispersive elements: a prism and a grism with respective resolutions of 30 and up to 260. When observations with spectrally dispersed light will not be possible for sensitivity reasons, narrow or broad band filters will be used and light will be dispersed spatially on the detector (the Airy disk then has a size of a few pixels).

A 3D view of the design of the dewar is presented in Figure 3. The cold box sits

Fig. 4. A view of MIDI in the integration hall at MPIA in Heidelberg. The optics in front are the warm optics. The metallic box in the back is the MIDI dewar.

on the bottom plate (the cold bench) which is delimited by the drive units and the vacuum valve. The size of the cold bench is 580×420 mm showing how compact MIDI is. The motor drive units are outside the cold envelope. Eight of them are necessary to move the MIDI mechanisms (filter wheel, spatial filters, focusing systems, beam splitters, cameras, dispersive elements, shutters). The vacuum pump are attached to the cryostat, so that it is evacuated on location. Mechanical and reflective optics parts are made in the same material so that MIDI remains aligned and focused when it contracts during cooling down.

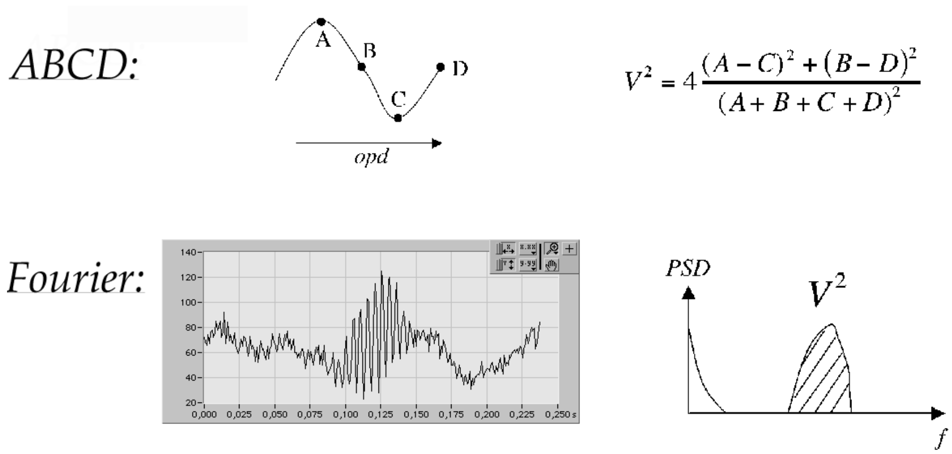


Fig. 5. The two modes of fringe measuring with MIDI. In the ABCD method, the central fringe is measured at regularly spaced $\lambda/4$ samples called A, B, C and D. The squared fringe contrast is the sum of the squared amplitudes of the two quadratures. In the Fourier method, a longer scan is performed and the squared fringe contrast is obtained by integration of the scan power spectral density at the fringe frequency.

5 The operating modes of MIDI

Although the instrument guideline was simplicity, MIDI offers a lot of flexibility in its use. Here we review the observing modes of MIDI.

5.1 Fringe measurements

MIDI is a coaxial interferometer and the fringe modulation is performed by scanning the fringe packet with the piezo delay line. Two scanning modes shown on Figure 5 will be available. The first one is called ABCD as a single fringe is scanned and measured at samples $\lambda/4$ apart. This mode requires that the central fringe be stabilized either externally with the VLTI fringe tracker if the source is bright enough in the near-infrared or internally by MIDI itself. It is therefore also a way to turn MIDI into a fringe tracker. In this mode, the squared fringe contrast is the sum of the squared amplitudes of the two quadratures. The second mode is called the Fourier mode. More fringes are scanned and the squared fringe contrast is obtained by integrating the scan power spectral density. It is not necessary to stabilize the central fringe in this mode. A variant of this method will allow to record fringes on sources whose signal is to low to allow direct fringe detection in a single scan. Power spectral densities will be co-added to make the fringe peak come out the noise. This mode is called the speckle mode. The only requirement for it is that the optical path difference (opd) be stabilized externally to within a few wavelentghs around the zero opd location.

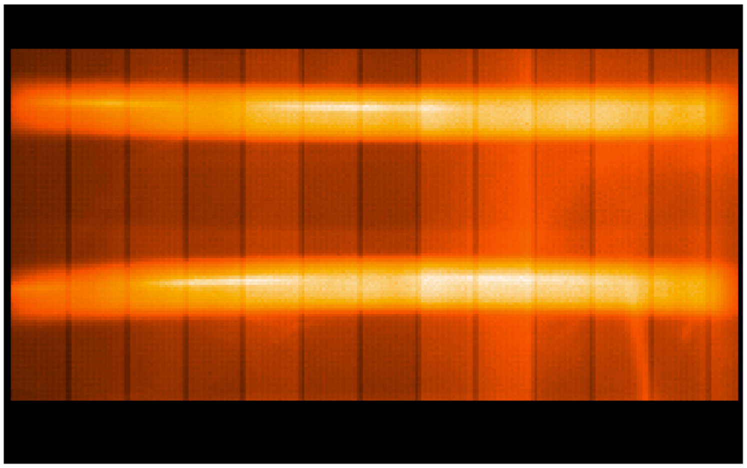
When single-mode spatial filters are used and sources are bright enough, the photometric beam splitters can be inserted to measure the total flux in each beam. These fluxes estimates are then used to normalize the interferometric signals (the low frequency component of the interferometric signals is then equal to one) and improve the accuracy of the visibility measurements. The reader is refered to the lecture by Alain Chelli in this book on data reduction for more details.

5.2 Spatial filters

The notion of spatial filtering has to be understood in a wide sense. MIDI has diaphragms of different sizes mounted on a slider that can be put at the intermediate focus of each beam. The larger diaphragm has the size of the VLTI field of 2 arcsec. Several slits are avaible whose lengths are equal to the maximum field and whose width varies from 1 to 4 λ/D. The signal is dispersed in the thinner direction, the other direction is used to image the field. The thinner slit is therefore single-mode in the spectral direction. Several sizes of pinholes ranging from 1 to 4 λ/D are also available . With the smaller pinhole the beam étendue is equal to the coherent beam étendue and the beams are spatially filtered to improve the quality of visibility measurements. If technologically possible, a single-mode fiber will also be available offering the best spatial filtering possible. The pinholes are in triplicate and aligned in the slit direction, their use will be detailed in the paragraph on background subtraction.

5.3 Spectral filters and dispersing elements

MIDI has a spectral capability primarily to avoid detector saturation by the background. The resolution is therefore limited not to degrade the sensitivity. This capability will of course be advantageous for astrophysical programs. There are two dispersing elements, a prism (R=30) and a grism (R=230). An example of dispersed interferometric signal recorded in the lab during integration is presented on Figure 6. The two strips are the two interferometric channels dispersed from 7.5 to 13 μm. The opd is fixed and the same for all λ. The alternations of bright and dark areas are produced by the dependence of phase with wavelength. As expected the phases in the two channels are opposite as a bright area in one channel corresponds to a dark area in the other one. The use of available narrow band filters is another possibility to increase the spectral resolution in the N band without dispersing.
When combining dispersed fringes and Fourier mode it is possible to perform an *a posteriori* coherent integration. As a matter of fact, the phase modulation frequency in the spectrum recorded for a given opd as on Figure 6 is equal to the opd. It is the peak location in the Fourier transform of the dispersed signal (interferogram is a function of λ, opd is fixed). Besides, for a given spectral channel the location of the fringe peak in the Fourier transform of an opd scan (interferogram is a function of opd, λ is fixed) gives the speed or first derivative of the differential piston. With a 2D Fourier transform the differential piston value and its



7.5 μm **13.0 μm**

Fig. 6. Channeled spectrum obtained with the grism. The two strips are the two interferometric outputs. The useful signal is roughly at the center of the strips. The beams are viewed through the largest pinhole and the shallower signal is therefore the background. The modulation due to the wavelength dependence of the phase is clearly visible. The phase is opposite in the two channels as the alternating bright and dark parts show.

first derivative can be estimated. From the record of successive scans it is possible to reconstruct the differential piston and to resample the interferograms to cancel out the atmospheric phase. Interferograms can then be co-added coherently. This method proposed by Cotton (1999) can improve the sensitivity of MIDI as the fringe peaks in the Fourier transforms can be detected in narrow bandwidths thus rejecting most of the noise. The coherent co-adding the interferograms is more efficient to reduce the noise than the co-adding of the DSPs in the speckle mode.

5.4 Background subtraction modes

We now focus on the methods to subtract the background from the MIDI signals. The traditional technique is to chop. The telescope direction of pointing is offset on the sky by a few arcseconds by tilting the secondary mirror to move the object out of the center of the field and record a background image. This background image is then subtracted from the object image to remove the background. This technique is illustrated by the left view of Figure 7. Unfortunately, the background measured at the offset position is not exactely the same as the one measured on-axis because the beam path hence the telescope background are not exactely the same. This technique is efficient to remove the average value of the background

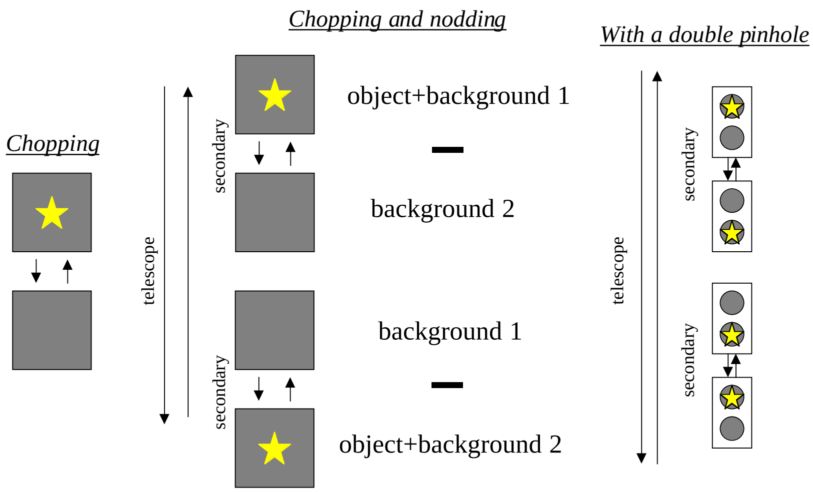


Fig. 7. Background subtraction methods. From left to right: *chopping*, the source is moved off the beam by tilting the secondary mirror; *chopping and nodding*, after the first chopping sequence the offset is applied to the whole telescope and the chopping sequence is resumed, the differential residual background is thus zeroed; *with a double pinhole*, same as chopping and nodding but two fields are permanently imaged allowing a 100% integration time on the source.

spatial distribution but not the gradient. To do so, the technique of nodding has been introduced. A chopping sequence is performed first. The telescope is then pointed a few arcseconds away from the source (for a point source) without tilting the secondary. The chopping sequence is resumed on the sky alone. This second chopping sequence allows to measure the higher orders of the background distribution and to remove it from the object. The flux of the object is measured 25% of the time only. The instrument efficiency can be increased if the object is put in the offset field after nodding the telescope as shown in the middle view of Figure 7. 50% of the observing time is then spent on the object. It is possible to spend 100% of the observing time on-source as shown on the right view by making all the offset positions coincide with the source position on the sky. The background residuals after the two chopping sequences are equal and cancel out. A double pinhole can be used instead of a single pinhole to do so. Compared to the previous method, the calibrated image is measured twice.

The chopping and nodding technique is well adapted to traditional observations with exposure times of a few hundreds of milliseconds to a few seconds. In interferometry, exposure times are generally imposed by the time scale of variations of the atmosphere. They become longer when a fringe tracker is used. Yet, in most accurate modes in which the effects of turbulence need to be measured, the exposure time is equal to the sampling time of the fringes, a fraction of the coherence time of the atmosphere. It is typically of 25 ms for MIDI hence a typical fringe frequency of at least 10 Hz. The switching time between on-source and background measurements can be of 200 ms (see Section (3)) and this is compatible with the chopping rate allowed by the VLT secondary mirrors. Yet, extra difficulties will rise as the interferometer requires that several servo loops systems be closed to operate properly: the telescopes control loops, the adaptive optics and the fringe tracking system. The last two loops are not required when off-source but they need to be closed to acquire the source. Also, typical of thermal infrared observations, a chopping sequence is necessary to center the source within the field of the instrument. All these constraints produce overhead times which are not negligible:

- moving the secondary mirror	20 ms
- closing the AO loop on the source	320 ms
- closing the fringe tracker loop (self or external)	320 ms.

These overheads may damage the instrument efficiency. The observing strategy needs to be adapted to the instrument properties, to the VLTI properties and to the characteristics of the background. This will come out of the commisioning phase. It is for example possible to be compliant with the 200 ms time difference between on-source and off-source measurements if the sequence of acquisitions is a series of elementary blocks of a source scan and then a background scan. Yet, reacquiring the source between elementary blocks will cost at least 660 ms making the instrument efficiency very low. Another possibility is to allow a repetition of N on-source scans followed by N off-source scans in an elementary block making the efficiency much better. The number N will result from a trade-off between visibility accuracy, instrument efficiency and background temporal spectrum. It is expected that the time spent to measure a science target and its calibrator will be of 15 minutes.
A new technique developped for MIDI may be very promising. MIDI is actually featuring a triple pinhole spatial filter rather than a double pinhole. The source would permanently be in the central pinhole. If the detector dark signal temporal variations are spatially stable then it will be possible to interpolate the background at the source position between the two bracketting background positions. No chopping nor nodding would be necessary. If this proves to work correctly the efficiency of MIDI will dramatically increase and the background subtraction will be perfect.

As a conclusion, subtracting the background is a critical issue but some solutions exist and some are very promising.

Table 2. Classes of science programs and goals studied by the MIDI consortium.

Classes of Objects	Goal	Number of objects	Fraction of UT time (%)
Active galactic nuclei	Dust torus	18	100
Young stellar objects	Geometry and disk structures	79	27
Extrasolar planets	Shift of light center and visibility modulation	4	100
AGB stars	Spatial distribution of dust components	54	5
Hot stars	Spatial distribution of dust components	11	3

6 Status and schedule

MIDI is being built by a european consortium led by the Max Planck Institut für Astronomie in Heidelberg (PI), astronomical institutes in the Netherlands coordinated by the Netherlands School for Astronomy (Co-PI for the Netherlands contribution), Observatoire de Paris (Co-PI for the French contribution) and Observatoire de la Côte d'Azur in Nice (chair of the science group) in France, the Kiepenheuer Institut für Sonnenphysik in Freiburg and the Thüringische Landesstenwarte in Tautenburg.
The manufacturing of MIDI parts started in August 1999 and the integration phase is in its last months after more than a year of labor in Heidelberg. Figure 4 shows the MIDI experiment with the warm optics at the front and the cryostat at the back. Integration of MIDI in Heidelberg will end by a Preliminary Acceptance in Europ of the instrument by ESO in the begining of September 2002. MIDI will then be shipped to Paranal and commissioning with siderostats and 8 m telescopes will start in December 2002. MIDI will therefore be operational for science observations in the period starting in April 2003.

7 Science program

The ISI instrument has pioneered high angular observations in the 10 μm window and has brought a lot of inputs for the understanding of late-type stars with a circumstellar dusty environment. MIDI will benefit of the VLTI environment and will go further. Extragalactic astrophysics will be within possibilities as well as other types of stellar and sub-stellar sources. Here we briefly present some science

cases of MIDI.
The science program of MIDI will be constrained by the sensitivity of the instrument, by the achievable spatial resolution and by the quality of the calibration. Before fringe tracking is available on VLTI, the limiting magnitude of MIDI with the 8 m telescopes is estimated to be N = 4 with the full N band corresponding to a minimum source flux of 1000 mJy (it is reduced by 3.3 magnitudes with the ATs, and by 0.9 magnitude with the resolution of 230 provided by the grism). This sensitivity is calculated on the basis of a sampling rate for the interferometric signal of 40 Hz. When fringe tracking becomes available, fringe motion due to atmospheric turbulence will be compensated and interferograms can be added coherently. The sensitivity should improve up to a factor of 100 if a total integration time of 15 minutes is assumed. This will enable observations on sources as faint as N = 9. As far as visibility calibration is concerned, the goal is to achieve a 1% accuracy on the brightest sources and routinely better than 5-10% in general. Since turbulence effects are reduced at 10 μm, the limiting factor will be the quality of the calibration of the background radiation.
Examples of topics for the science program of MIDI are presented in Table 2. They have been studied to prepare the MIDI consortium garanteed time program. The large number of objects selected is illustrative of the potential of MIDI and of its meaningful use by a wide community of astronomers. As the table shows, MIDI has a strong potential for astrophysics. The 8 m Unit Telescopes are definitely required for active galactic nuclei and for young stellar objects, two classes of objects which have almost not benifited from progresses in optical-infrared interferometry up to now (not at all in the case of extragalactic sources) and which are therefore important targets for the VLTI. The resolution of the VLTI at 10 μm (a 1 pc linear resolution at a 14 Mpc distance) will permit to resolve the central dust torus of a few AGNs and therefore to bring strong constraints on their geometry. For young stellar objects the sensitivity and resolution of MIDI will help solve the problem of the determination of the mass of young stars and the structure of their disks.
Direct detection of hot extrasolar planets will be one of the goals of MIDI. This program will be very challenging as it requires very high accuracy visibilities. The detection will be tried by searching the modulation due to the planet in the visibility and also by the shift of light center method which requires to accurately calibrate the spectral slope of the phase of visibilities by field inversion (Lopez & Petrov 1999).
AGB stars have been privileged targets of high angular resolution techniques. MIDI will make observations with both high angular resolution and medium spectral resolution possible. This program will be feasible with both 1.8 m and 8 m telescopes. The goals will be to explore the objects geometry including binarity and disk structure, to study the structure of outflows and to understand the dust and molecules formation processes.
MIDI will also address some other programs such as the study of the counterpart of Sagittarius A*, in the Galactic Center.

8 The future after MIDI

When operational, MIDI will be the first thermal infrared long baseline interferometer operating on a wide range of wavelengths. It will have opened a new field and one may wonder what will be the next steps.
Because of the high background level generated both by the atmosphere and the instrument, it is quite obvious that thermal infrared interferometry would benefit a lot from space-based observatories. The only existing plans for 10 μm interferometers are for planet spectroscopy with DARWIN in Europe (Léger *et al.* 1996) and the Terrestrial Planet Finder in the USA (Angel & Woolf 1997). Widening the investigation field of these instruments is under discussion. It is clear that extending their mission towards “regular” aperture synthesis imaging would be of great interest for several astronomical communities. As we have seen above, the background flux in a coherent beam étendue on VLTI is 500 Jy. It is reduced down to 1 mJy for DARWIN. The lower background level will make the sensitivity of DARWIN better than at least 7 magnitudes (based on the assumption of an increase in exposure time equal to the ratio of background fluxes between the ground and space based cases). Besides, the longer baselines of these space-based interferometers (1 km) will also increase the spatial resolution and the absence of turbulence will make imaging much easier. For science this means imaging with a 2 milli-arceseconds resolution thousands of faint objects (from young stellar objects to active galactic nuclei) with a program similar to those of millimetric interferometers.
Space is very attractive but the future of MIDI is also on the ground. The MIDI design permits a future extension of its wavelength range to include the Q band (17-25 μm). MIDI is a first generation instrument for the VLTI. Next generation thermal infrared beamcombiners will certainly allow the use of the four 8 m telescopes providing phase closures and therefore aperture synthesis imaging. An idea to re-use MIDI as a four-way beam combiner has been proposed by Lopez *et al.* (2002). The next generation will also include a nulling experiment at VLTI, possibly a nulling long baseline interferometer interferometer to define candidates for the DARWIN missions and to measure the amount of exozodiacal dust around candidate stars (Absil *et al.* 2002). The Keck interferometer will have the same kind of instrument to prepare TPF.

9 Conclusion

MIDI is within months to see first light at Paranal. The instrument has a unique potential with the long VLTI baselines, the large VLT pupils and the very good (u,v) coverage offered by the Auxilliary Telescopes. MIDI will face several challenges which triggered its concept and design. Being the first instrument of its class it will be the onset for a breakthrough in several astrophysical domains from AGB stars to Active Galactic Nuclei.

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