MIDI - the Mid-infrared interferometric instrument for the VLTI

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ABSTRACT

We describe the mid-infrared interferometric instrument MIDI which is planned to come into operation at the ESO Very Large Telescope Interferometer (VLTI) early in 2001.

Keywords: Interferometry, Mid-Infrared, VLTI

1. BACKGOUND

Interferometry with the ESO Very Large Telescope Interferometer (VLTI) on Paranal is planned to include the four 8 m telescopes (called 'unit telescopes' or UTs) as well as three relocatable outrigger telescopes of 1.8 m diameter (called 'auxiliary telescopes' or ATs). The development of VLTI is devided into phases. Phase A (until the end of 2001) will provide coudé optical trains on two unit telescopes, two delay lines, two test siderostats, two auxiliary telescopes, the control system and at least two beam-combining instruments[1]. For the subsequent phase B a third auxiliary telescope, coudé optics for the remaining two unit telescopes and two additional delay lines are foreseen. The beam combining instruments include a near-infrared imaging instrument (called AMBER) and the mid-infrared instrument MIDI to be described here.

2. RATIONALE FOR 10 MICRON INTERFEROMETRY AT THE VLTI

In general terms optical interferometry at 10 μm has both its advantages and disadvantages when compared to interferometry in the near-infrared or visible spectral range. First, direct interferometry in this wavelength range will be a new undertaking, promising new types of results or results on new types of objects. This will be qualitatively different from the otherwise quite succesful 11 μm heterodyne interferometry with the ISI instrument on Mount Wilson[2,3]. In addition, at this longer wavelengths mechanical requirements on the instrument will be considerably relaxed. On the other hand, a high thermal background has to be coped with. We estimate that for the VLTI the interferometric beams will have an emissivity of about 50 %, which corresponds to a flux of 1.25×10^{11} photons/s into an Airy disk of radius $0.26''$ (λ/D for an aperture of 8 m). Also the spatial resolution will be lower by about a factor of five than in the near-infrared. Nevertheless, mid-infrared interferometry appears an attractive choice.

This is particularly true for the VLTI interferometer which offers

- big apertures
  (8 m diameter, important because in the background-limited case S/N $\sim$ D^2)
- long baselines
  (up to 128 m, the spatial resolution being λ/D = 20 mas for a baseline of 100m)
- many telescopes
  (well, four of them, which translates into six readily available baselines)

In this combination the VLTI is unique among present-day optical observatories.

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3. SCIENCE PROGRAMME

The promising programmes possible within the above constraints are pretty much the same like in the near-infrared:

- binary stars, tests of early stellar evolution theory
- circumstellar disks, structure of protostars
- extrasolar planets (only detectable if quite hot, young or massive)
- brown dwarfs around nearby stars
- late-type stars and their dust shells
- AGN dust tori
- the counterpart of Sgr A*

This similarity of scientific programmes for the different interferometric instruments emphasises the view that the VLTI should be seen as one integral interferometric facility, with the planned two or three instruments allowing to study complementary aspects of the same objects.

4. BASIC PARAMETERS DEFINING THE INSTRUMENT

Most of the parameters defining the operation of the instrument are given by the atmosphere, some by the design of the VLTI delay line optics. However, the choice to observe only one baseline at a time was made to keep sensitivity.

Table 1. Basic parameters of the MIDI instrument

Telescope diameter	UTs ATs	8 m 1.8 m (used for bright sources)
Baselines		one at a time
Wavelength coverage	 expandable to	N band (8 μm - 13 μm) Q band (17 μ - 26 μm)
Field of view		$\pm$ 1$''$
Airy disk (FWHM)	at 10 μm	0.26$''$ (for 8 m telescopes) 1.14$''$ (for 1.8 m telescopes)
Atmospheric OPD jitter	rms	22 μm (at 10 μm)
Coherence time	at 10 μm	100 ms (for fringe measurement, fringe motion $\leq$ 1 μm)
Atmospheric stability	for chopping	200 ms
Differential dispersion	in 100m of air	0.9 μm (10 μm to 20 μm) 46 μm (1.6 μm to 10 μm)
Input beam diameter	from UTs from ATs	80 mm 18 mm
Detector pixel size		50 μm
Limiting magnitude	UTs at 10 μm ATs at 10 μm	5.0 mag (low accuracy mode) 1.8 mag (low accuracy mode)

The given limiting magnitude estimates refer to the case of self-fringe-tracking (bright sources) and the measurement mode without photometric monitoring of the instantaneous flux in the two telescope beams. For faint sources (not observable within one coherence time) external fringe stabilisation by a fringe tracker or by one of the near-infrared instruments is necessary to allow for coherent integration.

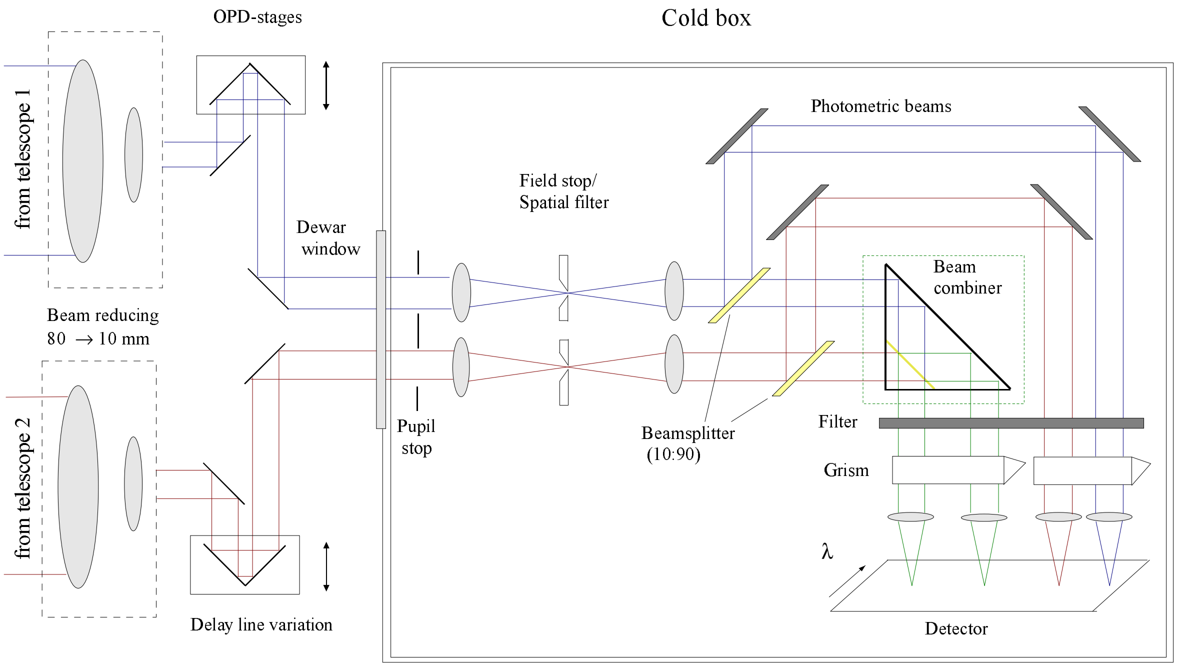

Figure 1. Schematic diagram of the instrument optics

5. GOALS

We will consider the instrument a full success if we achieve the following:

Point source sensitivity:	N = 5 mag (400 mJy)	in self-fringe-tracking mode, with 8 m telescopes and tip/tilt correction
	N = 11.5 mag (1 mJy)	with external fringe tracking
Accuracy of visibility:	5 %	faint sources, no spatial filtering
	1 %	bright sources, beam cleaning by spatial filtering
Phase measurement:	by external referencing	

6. PRINCIPLE OF MEASUREMENTS

The beams from two telescopes meet on a beam-combining beam splitter, where their pupils are superimposed “on axis” (i.e. with common beam axes, see Figure 1). The resulting two complementary outputs are imaged onto the same detector. Once the fringe is found, the intensity of the two outputs is modulated by stepping the optical path difference through one wavelength by means of the experiment-internal movable flat mirrors (”OPD-stages”) shown to the left of Figure 1. The fringe amplitude is determined from the modulating signal in one of the usual methods known from stellar polarimetry[4]. The large and not precisely known thermal background requires to determine the total flux separately by a chopped measurement, chopping between the object and an empty region of the sky. Dividing fringe amplitude by total flux the visibility is obtained. A grism in the parallel beam after beam combination provides moderate spectral resolution and at the same time keeps the detector from saturating.

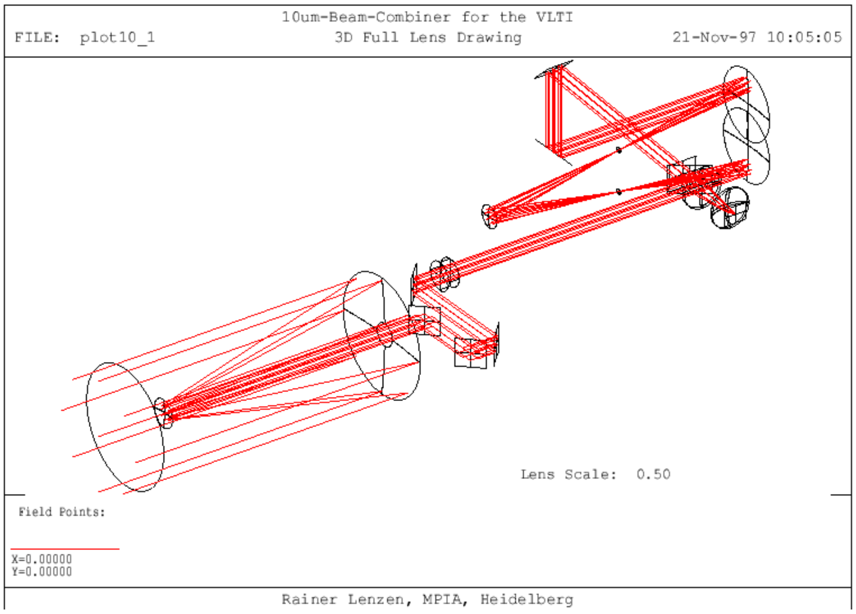

Figure 2. Optical layout of one beam of MIDI. The beam combiner is not shown in this figure for easier viewing. For details see text.

7. PRELIMINARY DESIGN

Satisfying solutions have been obtained both with lenses and with reflecting optics.
Figure 2 shows the present design for reflecting optics and one of the beams:

- horizontal part from left to right: beam-reducing cassegrain system, four flat mirrors for OPD modulation, entrance window, off-axis paraboloid (to the far right)
- vertical part from bottom up: two off-axis paraboloids on top of each other, including the one just mentioned, connected via two intermediate foci and an ellipsoidal mirror, followed by two flat mirrors. The beam combining beamsplitter (not shown) sits close to the upper flat, which recieves the transmitted beam, while the reflected beam is not shown to avoid crowding the diagram.
- transverse part from left to right: the upper flat mirror, a grism, the two-lensed camera optics, the detector (small four-quadrant rectangle projected onto the second camera lens).

The optics is essentially diffraction-limited with Strehl ratios of better than 90 % over most of the wavelength range and most of the field, putting about 70 % of the transmitted incoming light onto one pixel (50 μm in size). The overall transmission of the MIDI instrument optics is estimated to approximately 50 %.

The grism ("folded paper" just in front of the camera optics) provides a spectral resolution of a few hundred. Apart from its diagnostic value, this dispersion of the signal is used to dilute the strong background to a level which can be digested by the detector with its limited well capacity of about 10^7 electrons.

For visibility measurements of high accuracy, beam cleaning by focal diaphragms or by a single mode fiber between the two intermediate foci is foreseen. In this case, before combination, part of each beam has to be extracted and also to be imaged onto the detector. This will provide the photometric signals necessary to correct the fluctuating raw visibilities. The price for the improved accuracy is a loss in sensitivity.

8. END-TO-END MODEL

A computer model simulating the instrument, including the VLTI and the atmosphere is being used and being developed to verify instrument operation and concept. This development will be in close cooperation and make use of results of the end-to-end model of the VLTI[5].

9. PROJECTED START OF OBSERVATIONS

At present our plans are:	for commissioning:	early in 2001
	for the first scientific observations:	middle of 2001

10. PLANS FOR VLTI PHASE B

The obvious upgrades to be considered during a second phase of devolopment include the options

- to have more baselines simultaneously available (for phase closure)
- to provide an additional wavelength channel (20 μm)
- to go for higher spectral resolutions ($\approx$ 10000).

11. INSTITUTES INVOLVED

- Max-Planck-Institut für Astronomie, Heidelberg
  (carrying most of the cost and the manpower)
  Christoph Leinert (Project scientist), Uwe Graser (Project manager), Tom Herbst, Stefan Hippler, Reinhard Mundt, Rainer Lenzen (Optical design), Eckhart Pitz, Irene Porro (End-to-end model), Massimo Robberto, Ralf-Rainer Rohloff, Norbert Salm
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- Kiepenheuer-Institut Freiburg (Oskar von der Lühe), Thüringer Landessternwarte Tautenburg (Bringfried Stecklum)

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