Interferometry school Leiden 21.9.2000

MIDI: 10-μm interferometry with the VLTI

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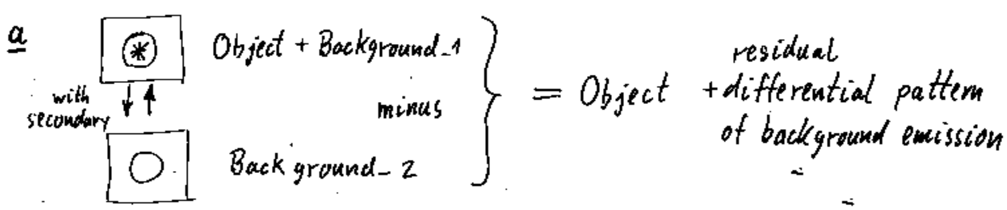
Observing on the 10 μm sky

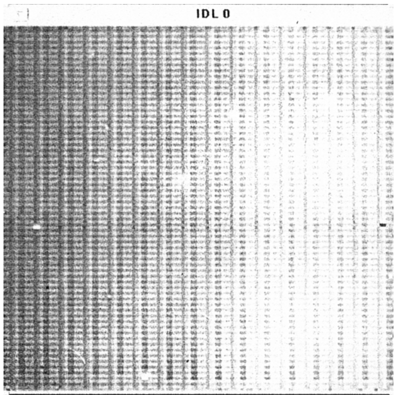
- sky is bright: N = -2 to -2.5 mag/□″ = 250 - 400 Jy/□″ ≙ $\tau_{sky} \approx 0.05$
- surface brightness ⇒ same flux into "Airy disk" $\pi(\lambda/D)^2$ independent of telescope size
  – hence S/N ratio $\sim D^2$
  – for N band on sky (8 μm - 13 μm): 2.6 x 10^{10} photons/s
- five minute integration ⇒ 7.8 x 10^{12} photons. Square root gives background limit of 3.6 x 10^{-7} of signal. ⇒ tremendous if not impossible stability requirements
- Solution CHOPPING: quick alternation between object and nearby sky background



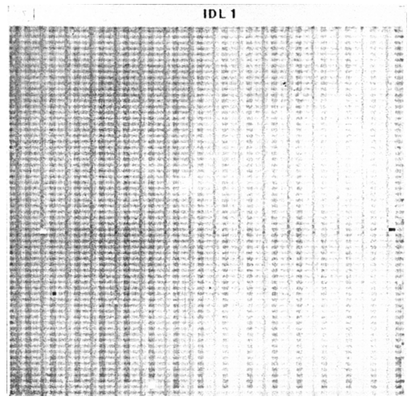
- Much more accurate thant "self sky subtraction" by flat-fielding

Background emission
α Boo @ 11.6 μm with MAX

N=3.3 mag
815 Jy



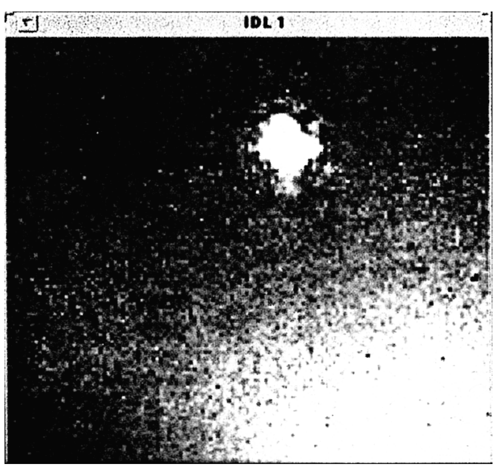
Source



sky

10 frames x 10.2 ms coadded …
…wait 20ms …
10 frames x 10.2ms coadded

Background subtraction with chopping



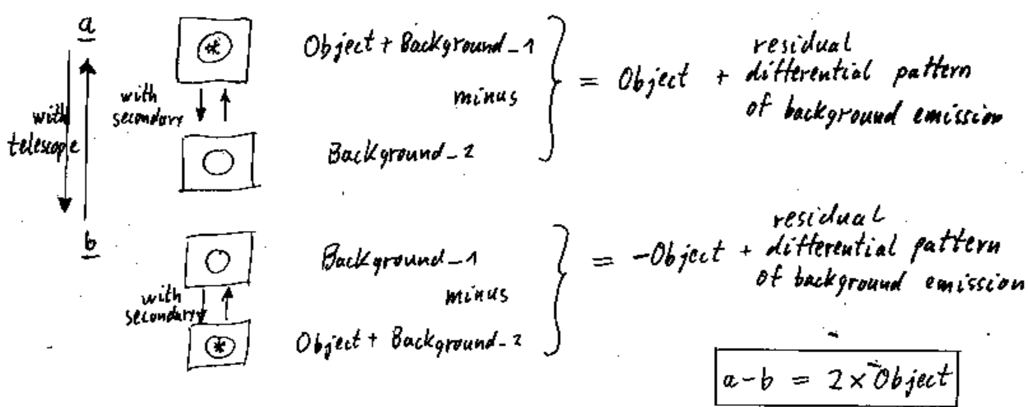
10x10ms on source - 10x10ms on sky

MAX on UKIRT Nov 1995

Observing on the 10 μm sky — continued

- Residual background correction by NODDING (telescope moves star into other beam)

= beam switching

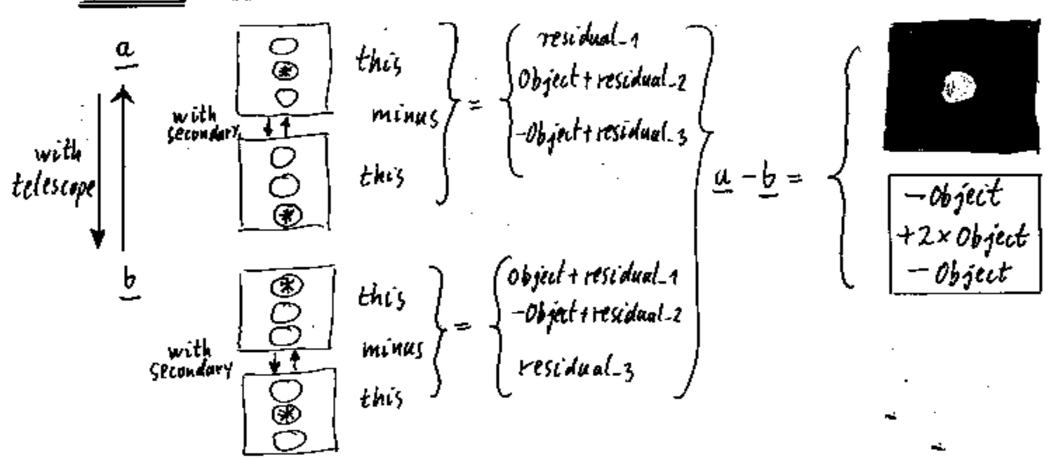


- This is the standard way of 10 μm observing.

but 50% off object

Observing on the 10 μm sky — continued

- ON-CHIP chopping and nodding



- This is the preferred way of 10 μm observing – accurate and efficient.
- MIDI needs the chopping/nodding capabilities synchronised on two telescopes of the VLTI.

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Additional constraints

- From the atmosphere:

  — Optical path difference fluctuation has rms $\approx 30\ \mu$m
  $\Rightarrow$ acceptable shift ($\lambda/10 = 1\ \mu$m) in 100 ms
  $\rightarrow$integration time limited to about this value

  — sky brightness fluctuations ("sky noise") occur at $\geq$ 200ms
  $\Rightarrow$ chopping frequency of $\approx$ 5 Hz needed

- From VLTI optical train:

  — transmission $\approx$ 40 %, i.e. emissivity $\approx$ 60 % in N band
  $\Rightarrow$ emission $\gg$ sky, $1.9 \times 10^{11}\ \gamma$/s per "Airy disk" on detector
  $\rightarrow$ does not fit into one pixel (full well $\approx 10^7$ electrons)

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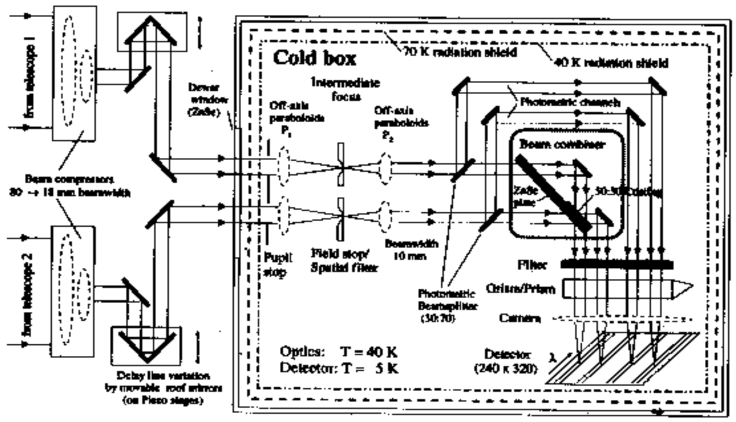
Characteristics of the MIDI instrument

– during first phase ("Phase A")* –

- **10 μm band, one baseline, measuring visibilities** (5% - 1%)
- **Spectral resolution:** filters, prism ($\lambda/\Delta\lambda$ = 30), grism ($\lambda/\Delta\lambda$ = 230)
- **Field:** Airy disk, fiber, long slit (λ/D×2″), field ±1″
- **Detector:** Raethyon Si:As blocked-impurity-band, 320x240 pixels, $\approx$1000 e^- read noise
- **Limiting magnitude on UTs:**

	self tracking (0.1s)	stabilised over 1000 s
white light	N=4.3 (0.7 Jy)	N=9.3 (7 mJy) fringe tracking
grism	N=1.4	N=6.4

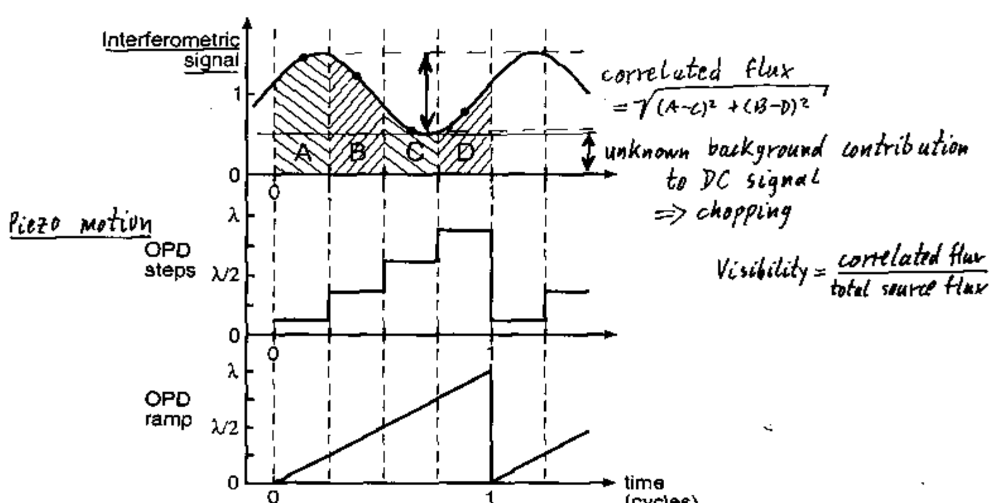
Schematic diagram of the optics of MIDI



Relative thermal radiation	
290K	5×10^{15}
77K	5×10^{9}
40K	170
35K	1
8K	5×10^{-61}
5K	≈ 0

Type of interferometry: on axis pupil plane combination
image plane detection

ABCD method (like Palomar Testbed)



$$\text{Visibility} = \frac{\text{correlated flux}}{\text{total source flux}}$$

Others:

- Fourier (like FLUOR, fast long scan, high accuracy)
- Coherent integration (fitting, high sensitivity)

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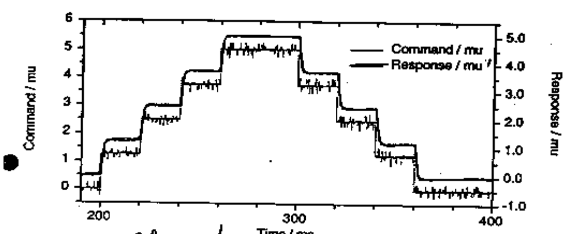
Potential problems

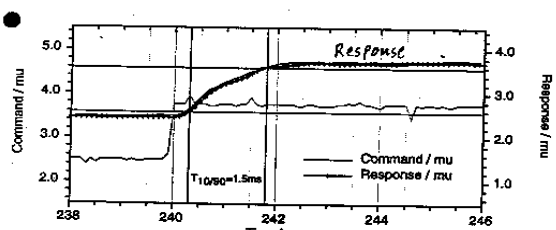
- **Piezo-driven mirrors**
  - how fast, stable, accurate?
- **Closed cycle cooler**
  - vibrations acceptable?
- **Chopping**
  - two telescopes synchronously
  - intertwined with fast interferometric measurements

fringe tracking!

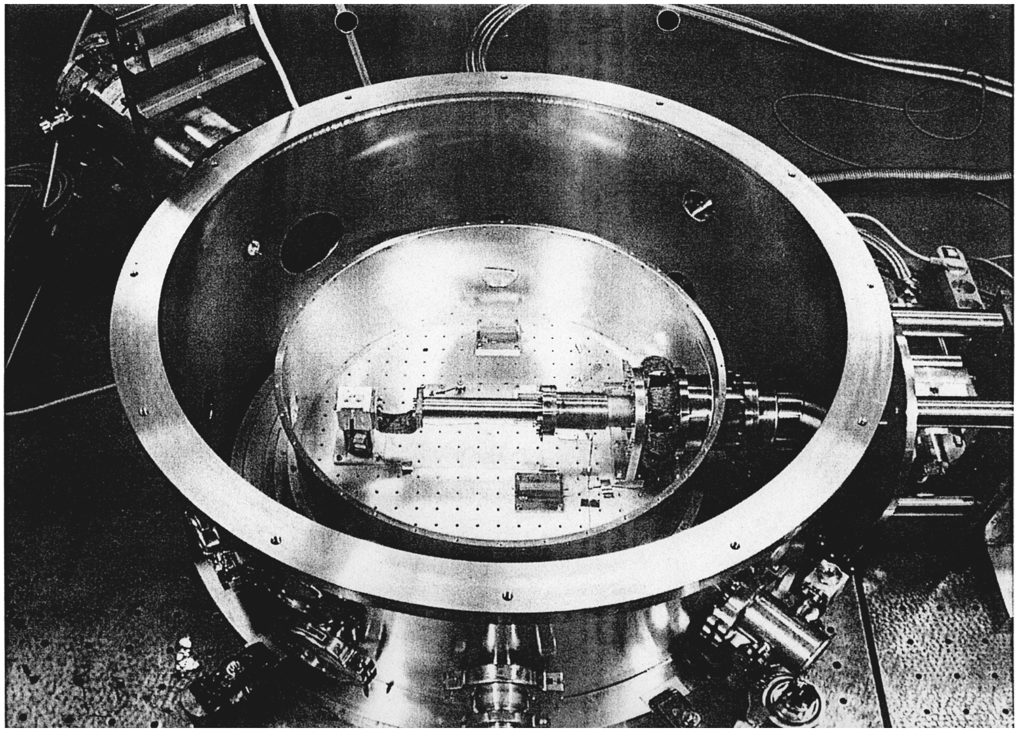
Piezo response

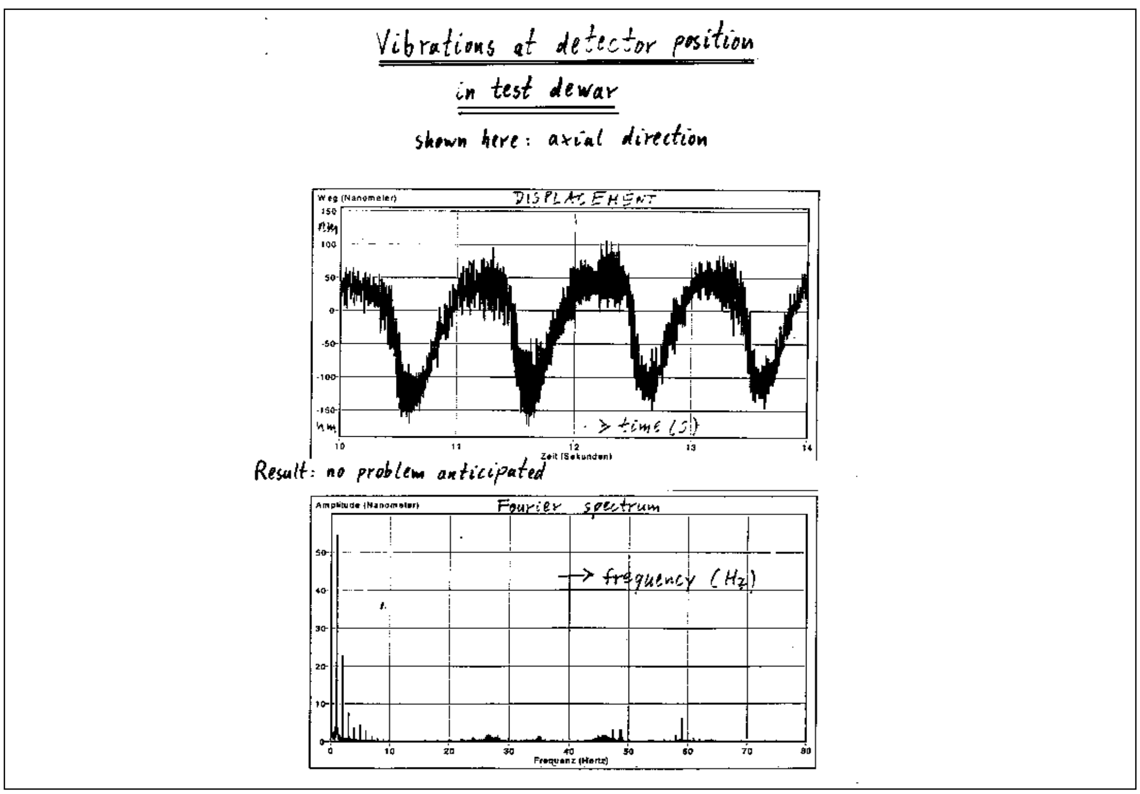


20ms steps

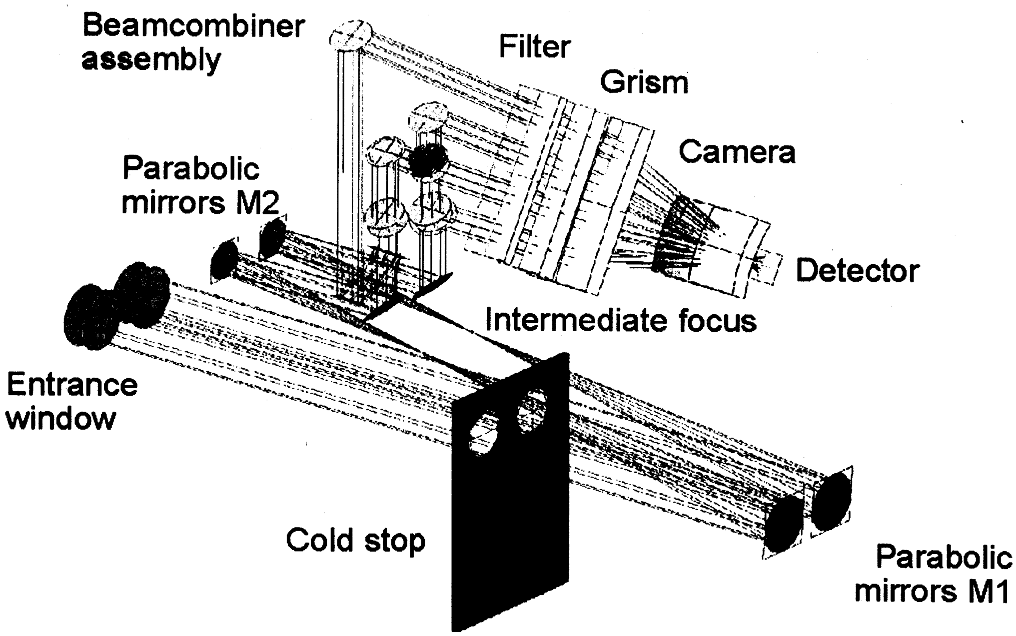


Enlargement: rise time 1,5ms

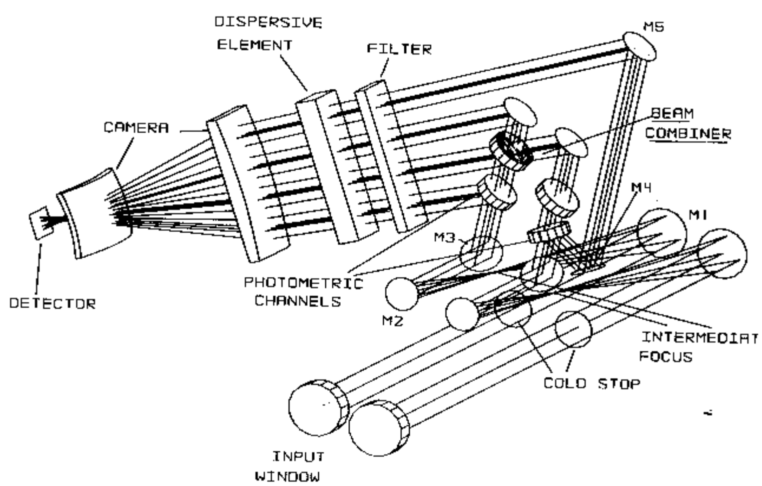



Vibrations at detector position
in test dewar
shown here: axial direction
Weg (Nanometer)
DISPLACEMENT
nm
→ time (s)
Zeit (Sekunden)
Result: no problem anticipated
Amplitude (Nanometer)
Fourier spectrum
→ frequency (Hz)
Frequenz (Hertz)

MIDI optics design



MIDI optics design



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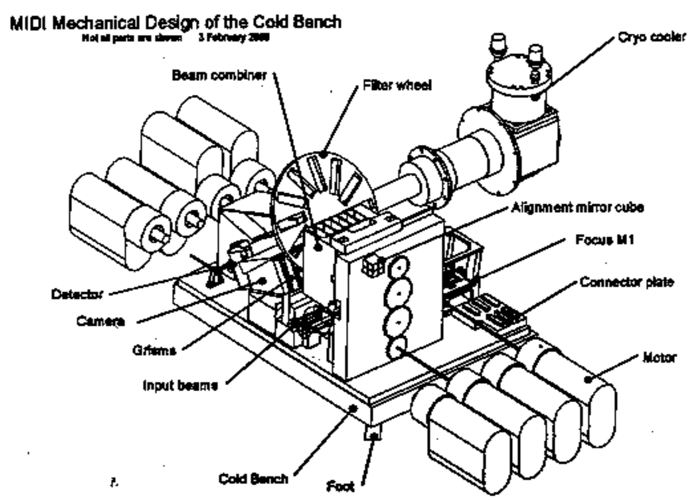
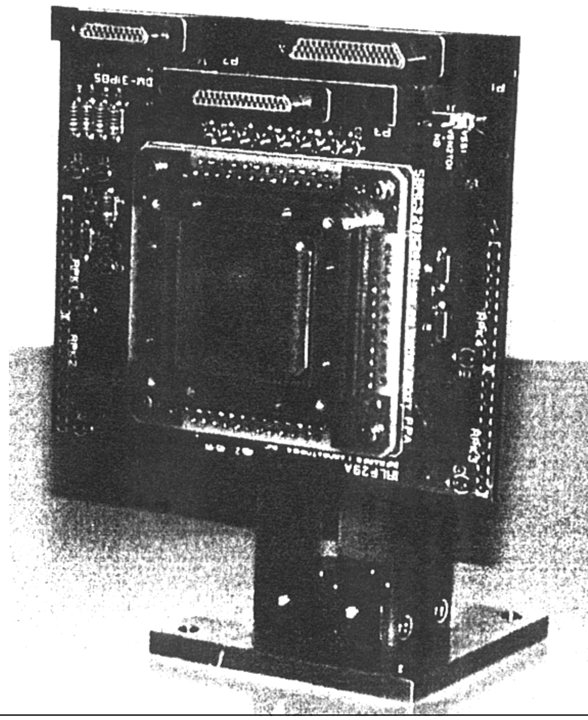
Choices in the optical setup

cameras:	field camera	λ/D = 3 pixels
	spectroscopic camera	λ/D = 1x2 pixels (two in spatial direction)
	pupil viewing camera	pupil diameter = 40 pixels
● **dispersing elements**	grism	resolution per pixel = 520
	prism	resolution per pixel = 60
	none	for observations with filter
filters	10 filters	narrow-band to full N band
focal plane	open	full $\pm 1''$ field
	slits	1-4 λ/D
	diaphragms	1-4 λ/D
	10 μ monomode fiber	best beam cleaning
● **photometric channel**	in	better accuracy
	out	better sensitivity

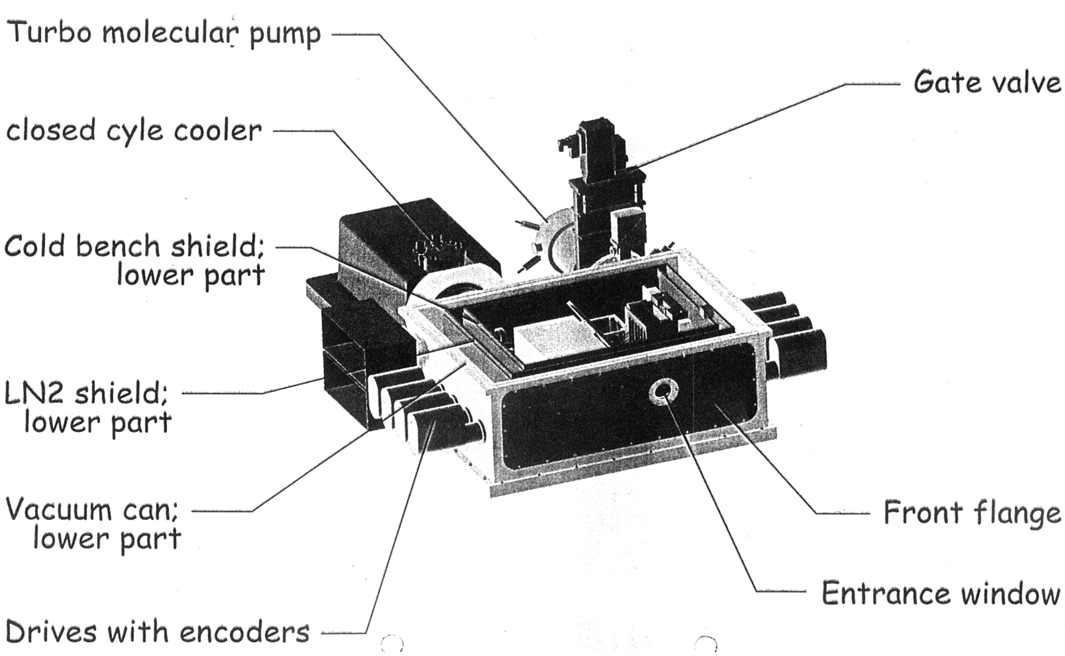
Mechanical design of the cold bench

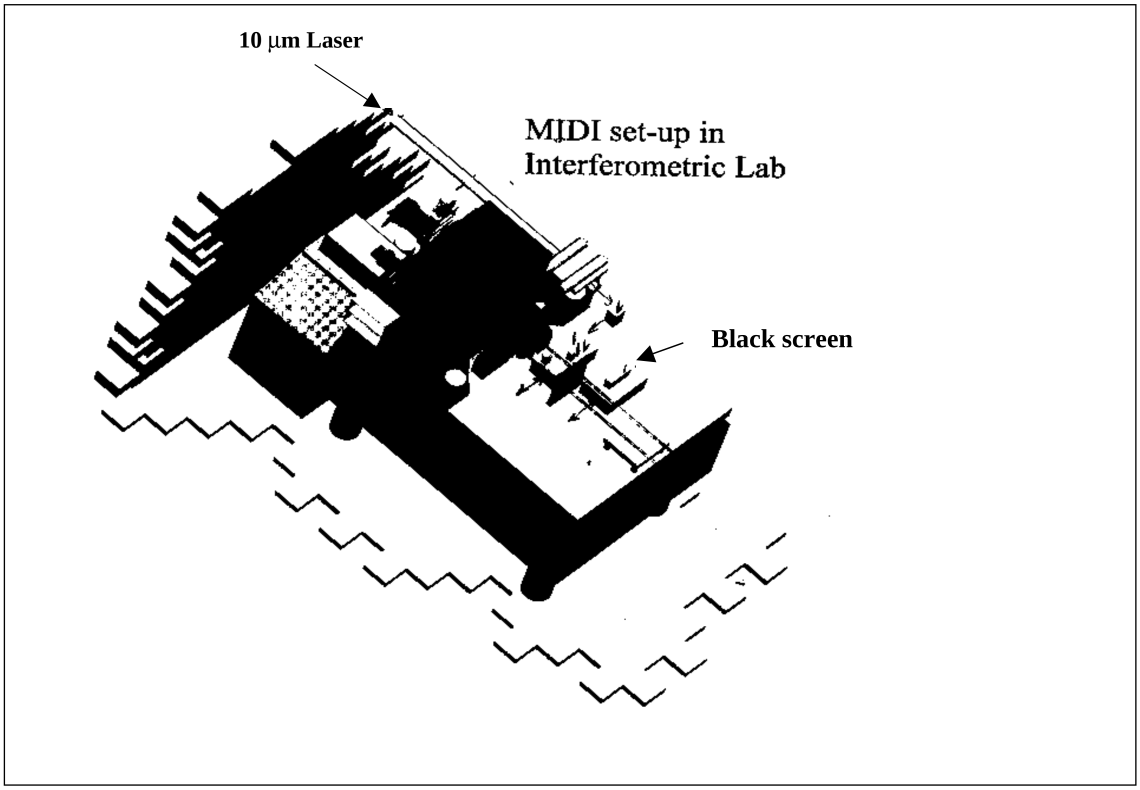


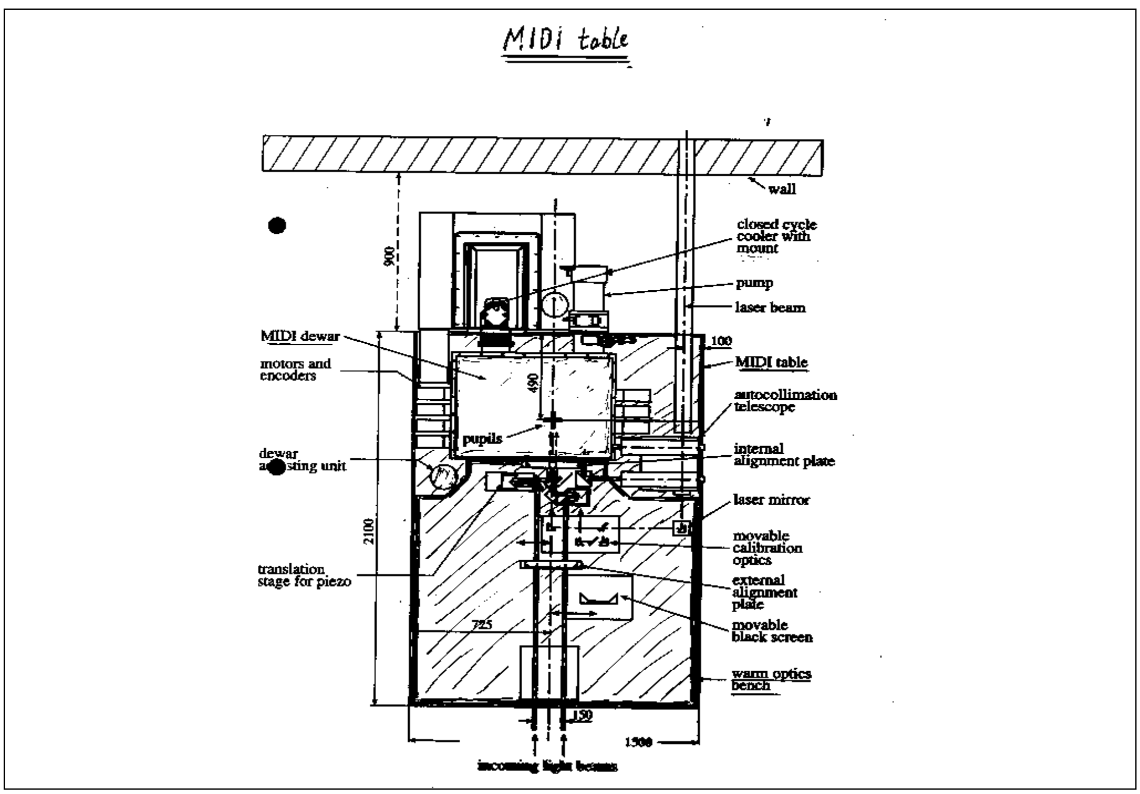
Detector mounting for tests

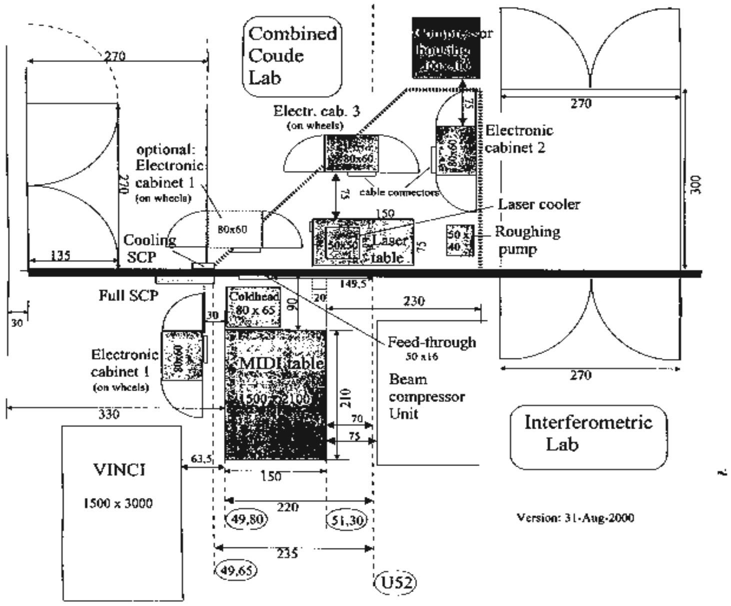


Detector plus multiplexer on chip carrier
↓
Pressed into socket
↓
Mounted on fan-out board




10 μm Laser
MIDI set-up in
Interferometric Lab
Black screen


MIDI table
wall
closed cycle cooler with mount
pump
laser beam
100
MIDI table
autocollimation telescope
internal alignment plate
laser mirror
movable calibration optics
external alignment plate
movable black screen
warm optics bench
MIDI dewar
motors and encoders
pupils
dewar
translation stage for piezo
900
490
2100
725
150
1500
incoming light beams



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Chopping reality

- relative sky noise: 1.0 at 5 Hz, 2.6 at 1 Hz, 6 at 1/minute, "$1/f$ spectrum"
- dead times for faint objects:
  – M2 settling 20 ms, Adaptive optics 320 ms, fringe tracker ≥ 320 ms
- Off-chip chopping with fringe tracking
  – time per 100 ms on-source: 100ms + 20ms + 100ms +20ms + 320ms + ≥320ms = ≥ 880 ms
  (on source, M2, on sky, M2, adaptive optics, fringe tracker)
  – noise: x 1.08 (4.2 Hz comparison object-sky)
  – time to reach theoretical accuracy of 100 ms: ≥ 1180 ms
- On-chip chopping with fringe tracking
  – time per 100 ms on-source: 100 ms + 20 ms + 320 ms + ≥320 ms = ≥ 760 ms
  (on source, M2, adaptive optics, fringe tracker → same on second position)
  – noise: x 2.44 (1.3 Hz comparison object-sky)
  – time to reach theoretical accuracy of 100 ms: ≥ 4.5 s
- ⇒ some kind of counterchopping or equivalent would help a lot.

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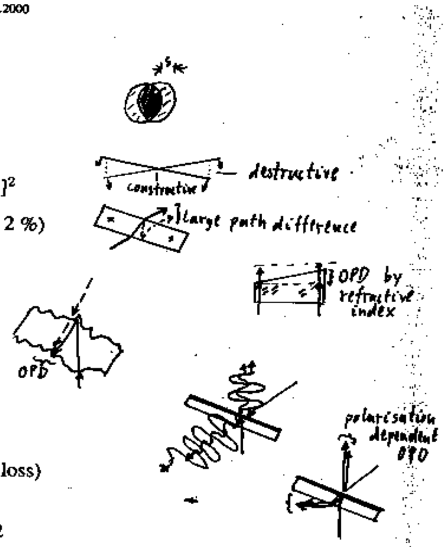
Coherence loss on the beam combiner

- beam overlap: $\pm$ 0.1 mm ($\leq$ 1% loss)
  coherence = overlap/beam = 1 - $sD/(\pi/4\ D^2)$
- beam tilt: $\pm$ 0.1 λ/D ($\leq$ 1% loss)
  coherence = average over beam = 1 - $\pi^2/8 \cdot [\text{tilt}/(\lambda/D)]^2$
- plate thickness: $\geq$ 5 mm (ghost fringes in side lobe < 2 %)
  coherence = $[\sin(\Delta OPD)/\pi\Delta OPD]^2$
- plate parallelity: < 10″ ($\leq$ 1 % loss)
  coherence = cos([ΔOPD]/2)
- surface quality: $\leq \lambda/8$ p-v [632 nm] ($\leq$ 2 % loss)
  coherence = $e^{-(\Delta\Phi)^2}$ (Δ of internal, external paths)
- splitting ratio: 0.40 < R, T < 0.60 ($\leq$ 4 % loss)
  coherence from amplitude mismatch = $\frac{2\sqrt{RT}}{R+T}$
- phase difference for s,p polarisation: $\leq$ 0.2 rad ($\leq$ 1% loss)
  coherence = cos([ΔOPD]/2)
- absorption < 0.02, reflection on passive surface < 0.02
  coherence = 1 - light loss



MIDI - Milestones

5-May-1997	MIDI kick-off
16/17 Jun-1997	First MIDI collaboration meeting
15 Jul-1997	ISAC meeting at ESO
● 16-17 Jul-1998	MIDI Concept meeting
15-Dec-1998	Concept Design Review at ESO
29-Jul-1999	Final Design review Optics
29-Feb-2000	Final Design Review MIDI ← we are here
● 15-Nov [redacted]-2000	Begin of instrument integration
≥15-Dec -2000	Begin of instrument tests
Nov [redacted] - 2001	Transport to Paranal
Dec - 2001	Commissioning with siderostats

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Fundamental physical constraints

- λ/D (λ = 10 μm, D = 8 m) = 0.26″ — *Diffraction*
  $\longrightarrow$ large image size (2x1.22x0.26″ = 0.63″) — *D = Telescope diameter*
- λ/B (λ = 10 μm, B = 130 m) = 16 mas — *Interference*
  $\longrightarrow$ low interferometric resolution — *B = baseline*
- B_λ(290 K, 10 μm) = 8.40 W m^{-2} sr^{-1} μm^{-1} — *Black body emission*
  B_ν(290 K, 30 THz) = 2.80 x 10^{14} Jy sr^{-1}
  $\longrightarrow$ high background radiation — *background-limeted observations*
- hν (1.98 x 10^{-20} Ws) $\approx$ 3/2 kT (4.0 x 10^{-21} Ws)
  $\longrightarrow$ detector has to be cooled (to below 10 K) — *cryo-vacuum*

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Rationale for 10 μm interferometry at the VLTI

- well adapted: 8 m aperture with tip/tilt $\longrightarrow$ diffration - limited
- big apertures of 8 m diameter
  (important, in background limit S/N ratio scales $\sim D^2$)
- long baselines
  (up to 130 m, giving a spatial resolution of λ/B = 16mas)
- four telescopes (i.e. six readily available baselines)
- new undertaking (new measurements on new objects)

In this combination the VLTI is unique and offers the best opportunities among present-day observatories.

one simply has to do 10μm interferometry at the VLTI

Science programme

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

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