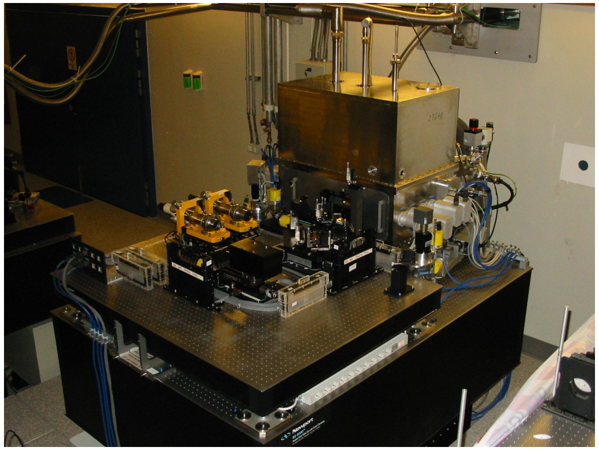
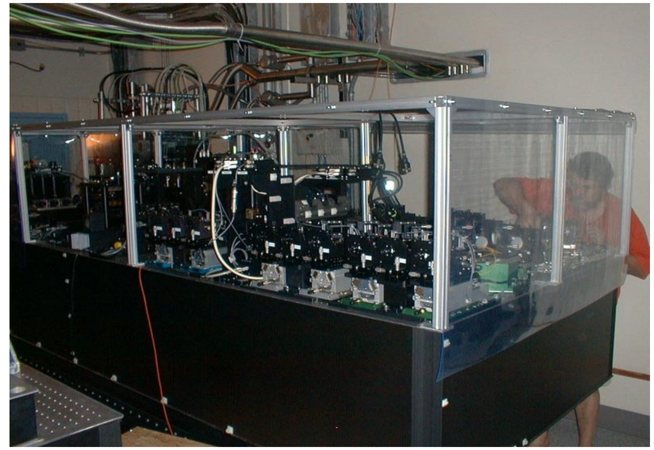
AMBER & MIDI instruments - the user's point of view





Euro Summer School

Active Galactic Nuclei at the highest angular resolution: theory and observations

Torun, Poland

27 August - 7 September, 2007

Markus Wittkowski

User Support Department (USD), ESO Garching

1 September 2007

Outline

- The MIDI instrument.
- The AMBER instrument.

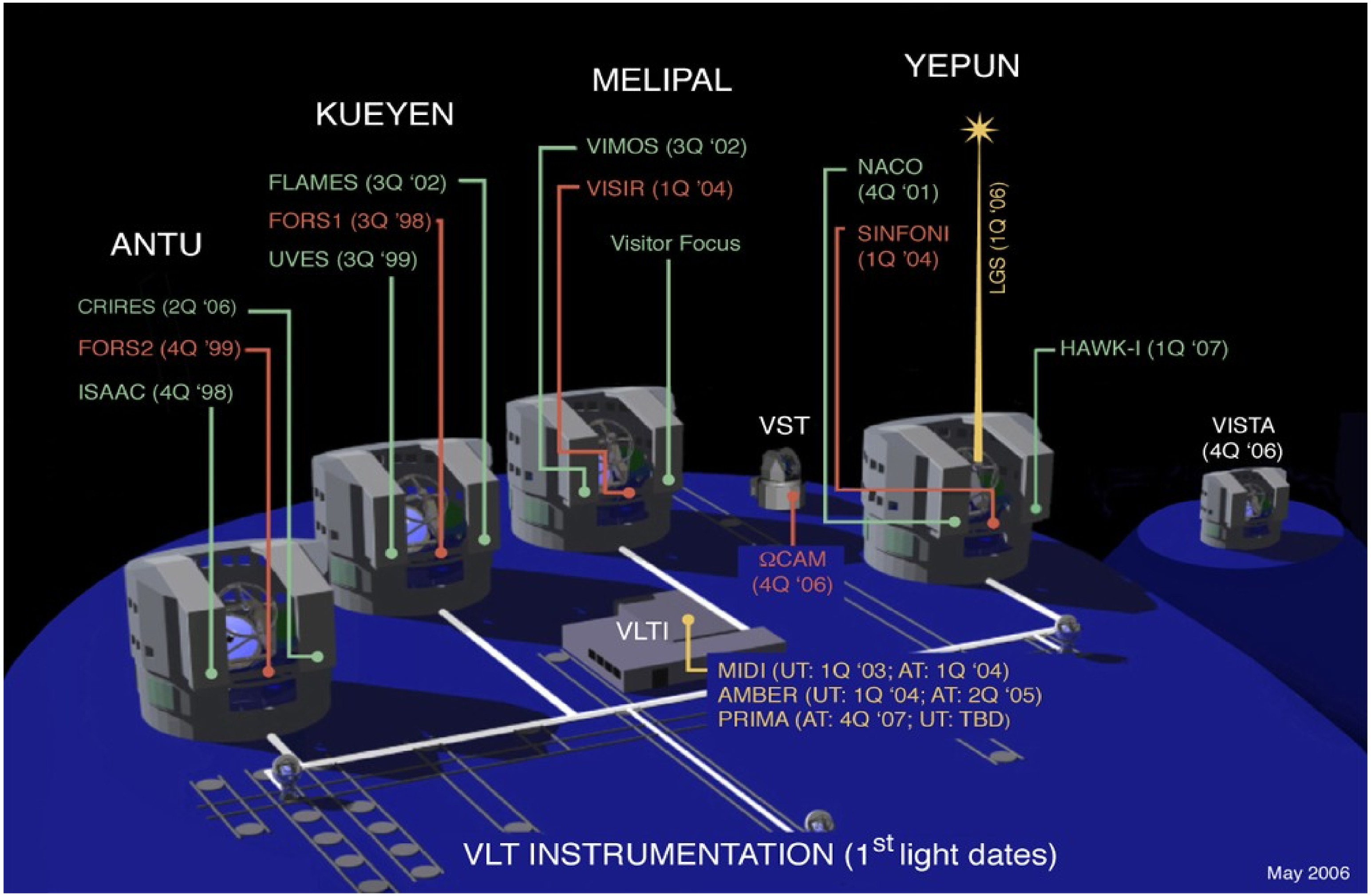
- Observing with the VLTI
- ESO observation preparation tools VisCalc and CalVin.

Not covered in this lecture:

- Theory of interferometry -> Haniff
- Visibilities, phases, UV space -> Millour, Young
- The VLTI facility -> Schöller

- AMBER/MIDI data reduction -> Le Bouquin

VLT/VLTI instruments



VLTI instruments and their operation are fully integrated into the general scheme of the VLT instruments.

VLTI Instruments

- **VINCI**: *K*-band

- **MIDI**: Mid-Infrared (8-13 μ m) 2-way beam combiner.

  Spectral resolution R=30 (prism), R=230 (grism).

  Result: One visibility spectrum per observation (+photometric spectrum).

- **AMBER**: Near-Infrared (*J, H, K*; 1-2.5 μ m) 3-way beam combiner.

  Spectral resolution R=30 (low resolution), 1500 (medium r.), 12000 (high r.).

  Result: 3 visibility spectra and 1 closure phase spectrum per observation.

- PRIMA: Phase Referenced Imaging and Micro-arcsecond Astrometry.

  -> Lecture by Francoise Delplancke.

Reading

Regularly updated ESO sites:

- AMBER : http://www.eso.org/instruments/amber
  AMBER user manual, AMBER template manual
- MIDI: http://www.eso.org/intruments/midi
  MIDI user manual, MIDI template manual
- Phase 1: http://www.eso.org/observing/proposals/
  Call for proposals (CfP)
- Phase 2: http://www.eso.org/observing/p2pp
  Service mode guidelines. AMBER- and MIDI- specific pages.

Further literature on the instruments

- AMBER:

AMBER, the near-infrared spectro-interferometric three telescope VLTI instrument, Petrov et al. 2007, A&A, 464, 1-12

Optical configuration and analysis of the AMBER/VLTI instrument, Robbe-Dubois et al. 2007, A&A, 464, 13-27

- MIDI:

Scientific observations with MIDI on the VLTI: present and future, Leinert 2004, SPIE, 5491, 19

Mid-infrared sizes of circumstellar disks around Herbig Ae/Be stars measured with MIDI on the VLTI, Leinert et al. 2004, A&A, 423, 537

- VLTI:

Observing with the ESO VLT Interferometer, Wittkowski et al. 2005, The Messenger 119, 15

AGN: Scientific results based on optical interferometers

- Swain et al. 2003, ApJ, 596, L163, Keck/near-IR,
  "Interferometer Observations of Subparsec-Scale Infrared Emission in the Nucleus of NGC 4151"
- Wittkowski et al. 2004, A&A, 418, L39, VLTI-VINCI/near-IR,
  "VLTI/VINCI observations of the nucleus of NGC 1068 using the adaptive optics system MACAO"
- Jaffe et al. 2004, Nature, 429, 47, VLTI-MIDI/mid-IR,
  "The central dusty torus in the active nucleus of NGC 1068"
- Poncelet et al. 2006, A&A, 450, 482, VLTI-MIDI/mid-IR,
  "A new analysis of the nucleus of NGC 1068 with MIDI observations"
- Meisenheimer et al. 2007, A&A, 471, 452, VLTI-MIDI/mid-IR,
  "Resolving the innermost parsec of Centaurus A at mid-infrared wavelengths"

Other scientific papers based on AMBER & MIDI data

- AMBER

Young stellar objects: Malbet et al. 2007, A&A, 464, 43; Tatulli et al. 2007, A&A, 464, 55

LBV □ Car: Weigelt et al. 2007, A&A, 464, 87

B[e] stars: Domiciano et al. 2007, A&A, 464, 81; Lachaume et al. 2007, A&A, 469, 587

Be stars: Meilland et al. 2007, 464, 59 & 73

Nova RS Oph: Chesneau et al. 2007, A&A, 464, 119

Wolf-Rayet binary: □ □ Vel: Millour et al. 2007, A&A, 464, 107

- MIDI

AGN: Jaffe et al. 2004, Nature 429, 47; Poncelet et al. 2006, A&A, 450, 235; Meisenheimer et al. 2007, A&A, 471, 453

Young stellar objects: Leinert et al. 2004, A&A, 423, 537; van Boekel et al. 2004, Nature, 432, 479; Preibisch et al. 2006, A&A, 458, 235; Quanz et al. 2006, ApJ, 648, 472; Abraham et al. 2006, A&A, 449, L13

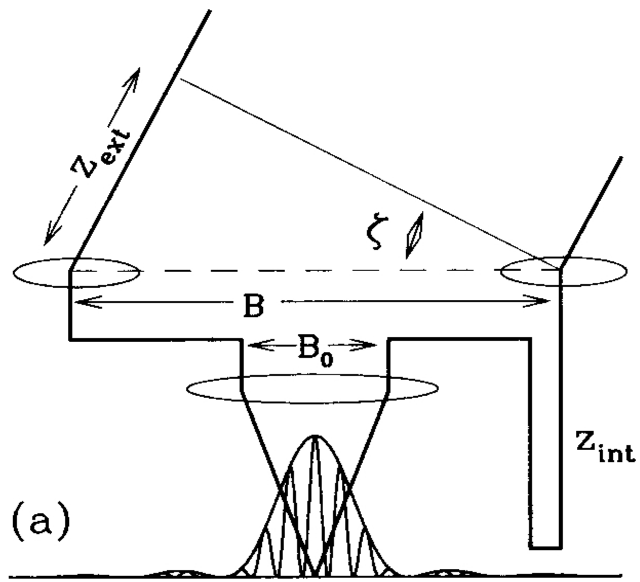
AGB & post-AGB: Ohnaka et al. 2005/2006, A&A 429, 1057/445, 1015; Deroo et al. 2006, A&A, 450, 181; Matsuura et al. 2006, ApJ, 646, L123; Chesneau et al. 2006, A&A, 455, 1009; Ohnaka et al. 2007, A&A, 466, 1099; Wittkowski et al. 2007, A&A, 470, 191

LBV ▪ Car: Chesneau et al. 2005, A&A, 435, 1043

Beam combination

AMBER

Image plane
(“Fizeau”)

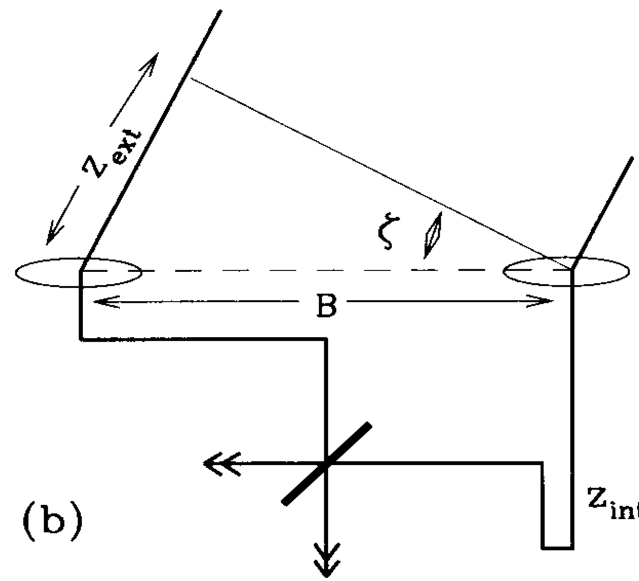


Spatial fringe detection

(geometric delay)

MIDI

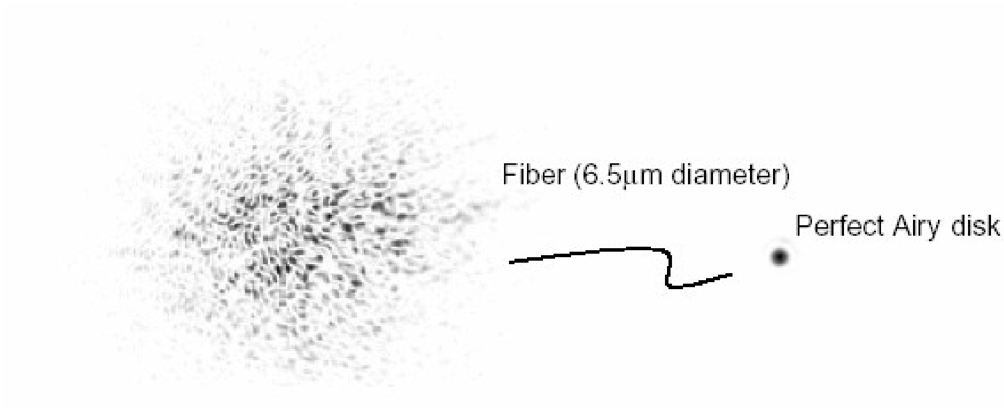
Pupil plane
(“Michelson”)



Temporal fringe detection

(temporal delay modulation)

Spatial filtering



AMBER

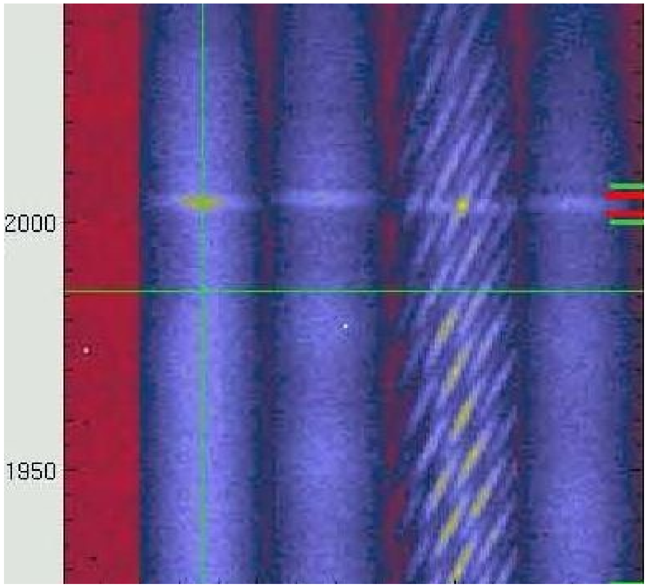
MIDI

Single-mode optical fibers
Separated for J, H, K

Pinholes, slits.

Photometric calibration

AMBER



The photometric signals corresponding to the three incoming beams and the inteferometric signal are always taken simultaneously.

MIDI

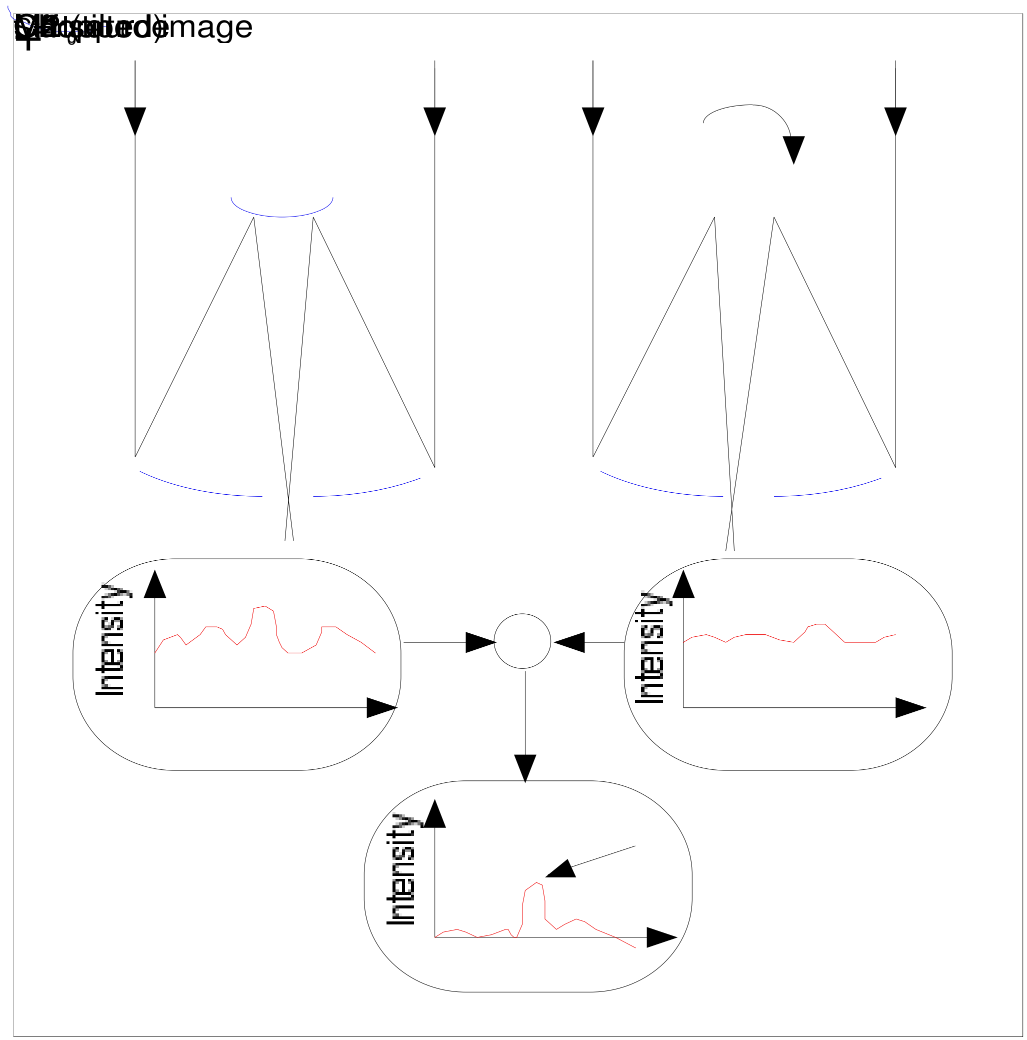
HIGH_SENS mode:
First only the interferometric signal is recorded. Then, the beam combiner is moved out and the photomeric signal Is recorded sequentially.

SCI_PHOT mode:
Beamsplitters are used to record the interferometric signal and the photometric Signal simultaneously.

Thermal infrared: CHOPPING for MIDI

- Sky glows with spatial and temporal fluctuations of intensity (H_2O vapor).
- Thermal emission of optics proportional to $\varepsilon \ T^4$
- Mirrors: $\varepsilon \approx 0.05$

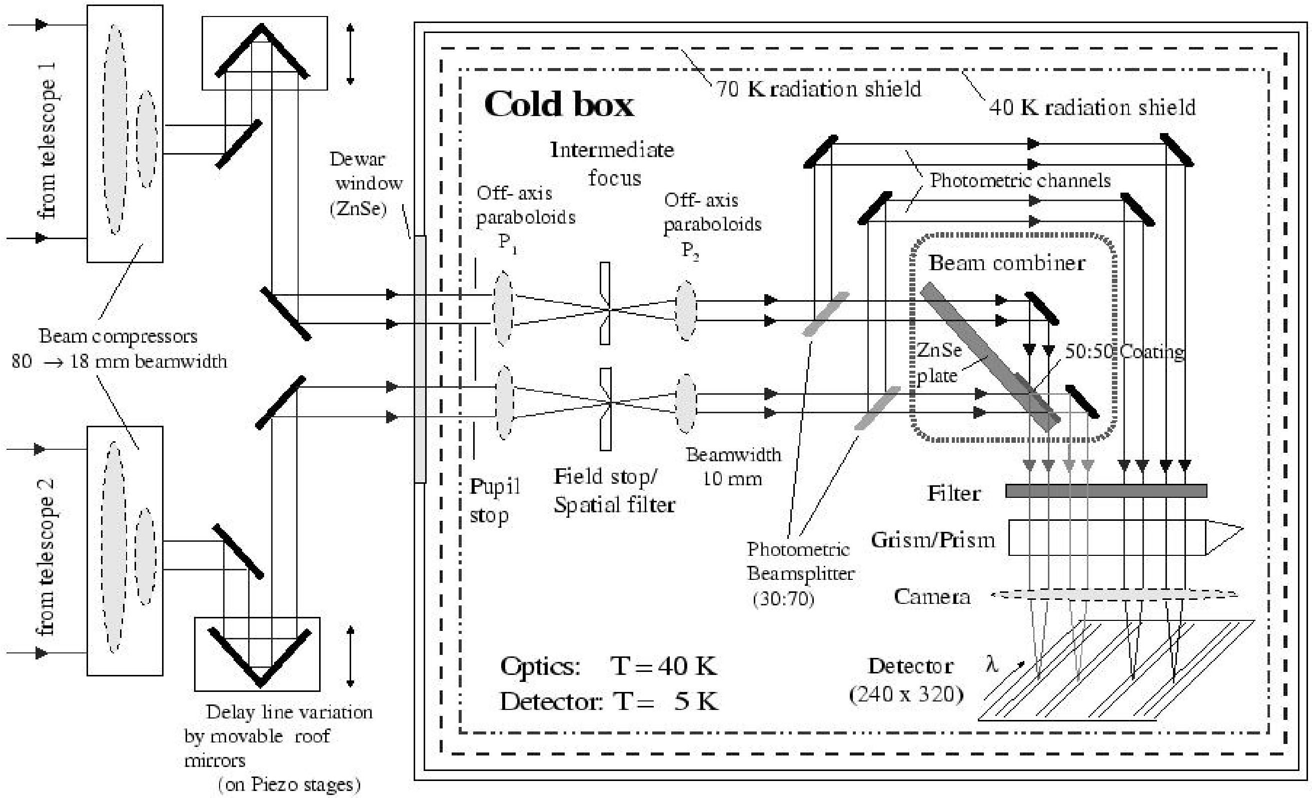
⇒Requirement for chopping for photometric exposures (typically 2 Hz)



Overview of MIDI and AMBER

	MIDI	AMBER
Beams	2	3
Beam combination	Pupil plane	Image plane
Wavelength	8-13 μ m	1-2.5 μ m
Spectral resolution	30 (Prism); 230 (Grism)	30 (LR); 1500 (MR); 12000 (HR)
Limiting magnitude UT	*N*=4 (current) *N*~9 (FSU in K)	*K*=7 (current) *K*~10 (FSU), *K*~18 (PRIMA)
Limiting magnitude AT	*N*=0.74 (current), *N*~5-6 (FSU in K)	*K*=5 (in all modes with FINITO) *K*~8 (FSU), *K*~15 (PRIMA)
Visibility accuracy	<10-20% (1-5%)	1% (diff.), 3% (abs.), current 2-10%
Airy disk FOV	0.26'' (UT), 1.14'' (AT)	60 mas (UT), 250 mas (AT) in *K*
Spatial resolution, 200m	10 mas	1 mas (*J*), 2 mas (*K*)
UT First Fringes	December 2002	March 2004
Regular observations	Since April 2004	Since October 2005
Consortium	D/F/NL (PI Ch. Leinert)	F/D/I (PI R. Petrov)

Principle of MIDI - the MID- infrared Interferometer for the VLTI



- Light arriving from 2 UTs or 2 ATs, corrected by MACAO or STRAP, IRIS (laboratory tip-tilt), FINITO.
- Time-modulated OPD variations to generate interferograms (warm optics).
- Pupil stops to reduce background and stray-light (cold optics).
- Light focused on field stops (pin-holes for spatial filtering, slits, or full-field).
- Re-collimation, optional 30/70 beam-splitters to obtain simult. photometry (HIGH_SENS/SCI_PHOT).
- Beam-combination (pupil plane) by 50/50 beam-splitters.
- Spectral filter. Dispersion by prism or grism.
- Focused onto the detector with fast read-out (fringe detection and feedback to delay line).

AMBER principle

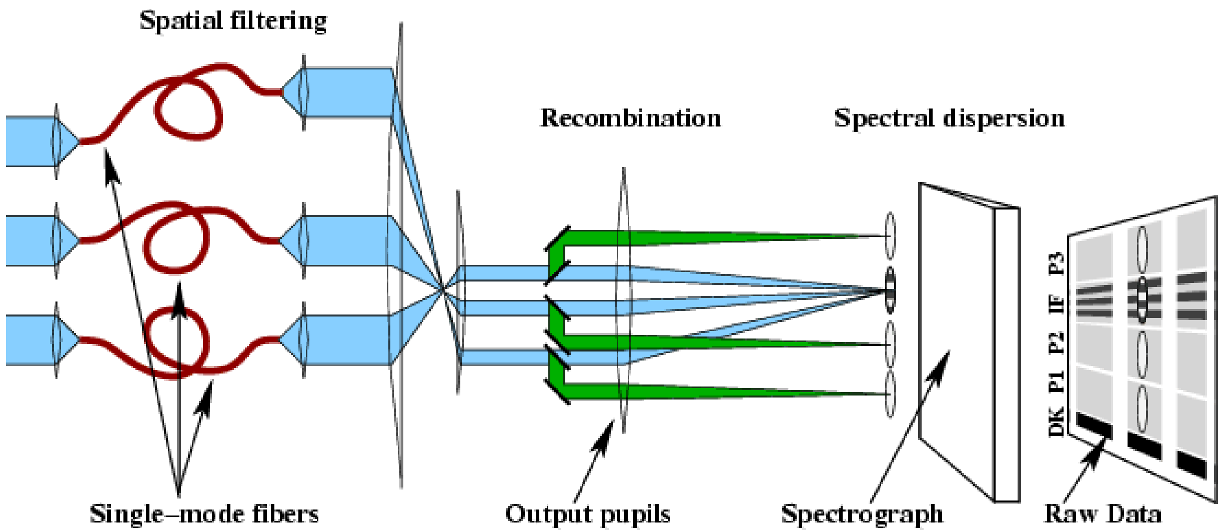
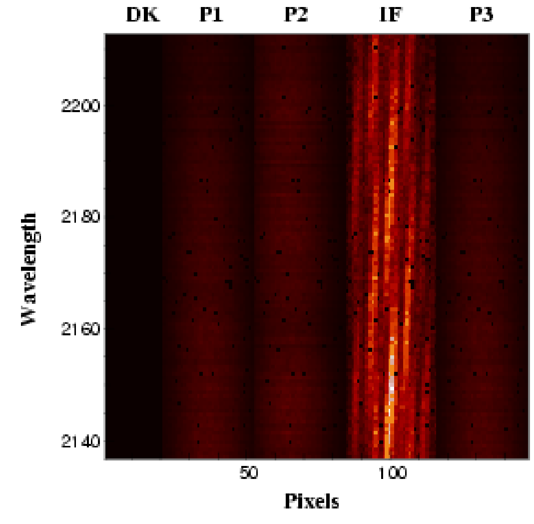


Fig. from Tatulli et al. 2007



- Warm optics: Dichroic plates separate the *J,H,K* bands, light is injected into single mode fibers for spatial filtering, and the *J,H,K* light is again combined so that the airy disks for each band have the same size. Photometric channels are separated.
- The three collimated beams form a non-redundant set up, and are focused into a common Airy pattern that contains the fringes (beam combination in image plane).
- In addition: Cylindrical optics to reduce noise, neutral density filters, polarisers.
- Spectrograph: Dispersion by a standard long-slit spectrograph (3 different spectral resolutions of R = 30, 1500, 12000). Includes an image plane cold stop and a cold pupil masks.
- Detector: One quadrant of a 1024x1024 pixel Hawaii detector.

What measures AMBER

- Absolute visibility in each spectral channel (3% accuracy).
- Relative visibility, i.e. ratio of the visibility in each spectral channel and the visibility in a reference spectral channel (1% accuracy).
- Phase difference, i.e. the phase in each spectral channel and the phase in a reference spectral channel.
- Closure phase.

Chronicle of VLTI observing periods

	March 2001	First fringes with VINCI/siderostats
P70/71	Oct 2002 - Sep 2003	Shared risk VINCI observations
P73	Apr 2004 - Sep 2004	Regular MIDI/UT observations
P76	Oct 2005 - Mar 2006	MIDI/AT observations added AMBER/UT observations added
P79	Apr 2007 - Sep 2007	AMBER/AT observations added

In total during P73-P80 (April 2004 to present):
141 AMBER programs, 194 MIDI programs, or 309 VLTI programs.

66 different AMBER PIs, 72 different MIDI PIs, 116 different VLTI PIs from 15 countries.

The ESO telescope bibliography lists 71 refereed papers directly based on VLTI data, of which 39 papers are based on VINCI data, 28 on MIDI data, and 9 on AMBER data (as of 24 August 2007).

Specific Requirements for Interferometry (I): Calibration

- The measured visibility function needs to be calibrated for the atmospheric and instrumental transfer function.
- This implies the need for alternating observing sequences of science targets and calibrators.

- The observer is requested to provide a calibration star OB for each science star OB. The two OBs are executed in a row and are considered successfully completed if each of them was executed successfully.

  Different pairs of science/calibrator OBs are executed independently.

  Option to request additional calibration star data in service mode.
- In the course of the night, this leads to an alternating observing sequence. Data taken on calibrators are public once they arrive in the archive.
- The selection of calibration stars is supported by the ESO tool “CalVin” based on different user-defined criteria.

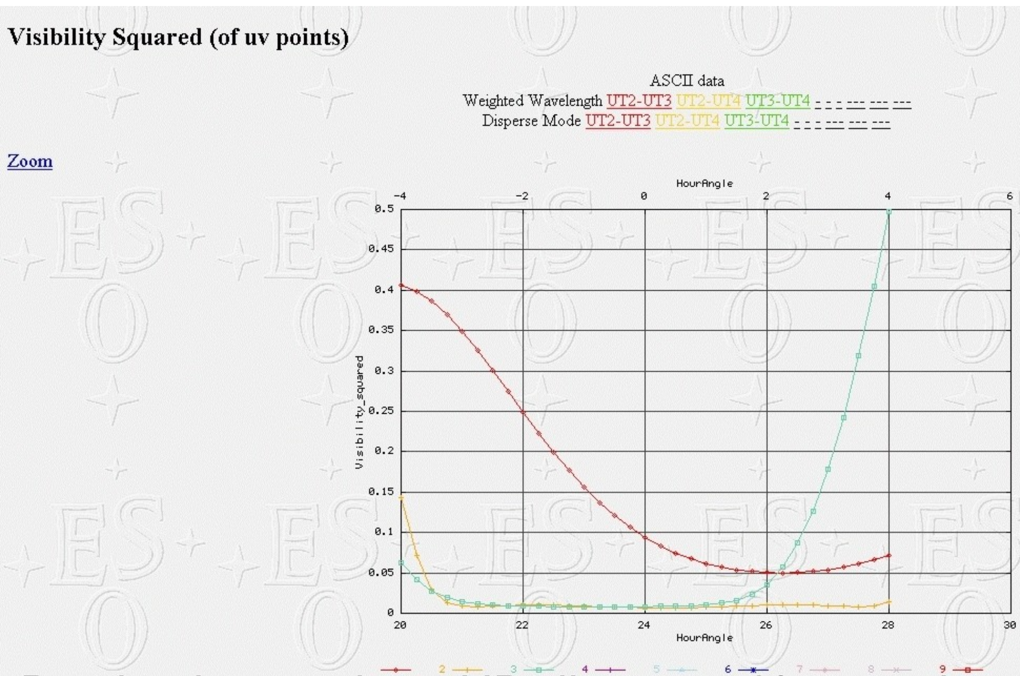
Specific Requirements for Interferometry (II): Combination of different baselines (aperture synthesis)

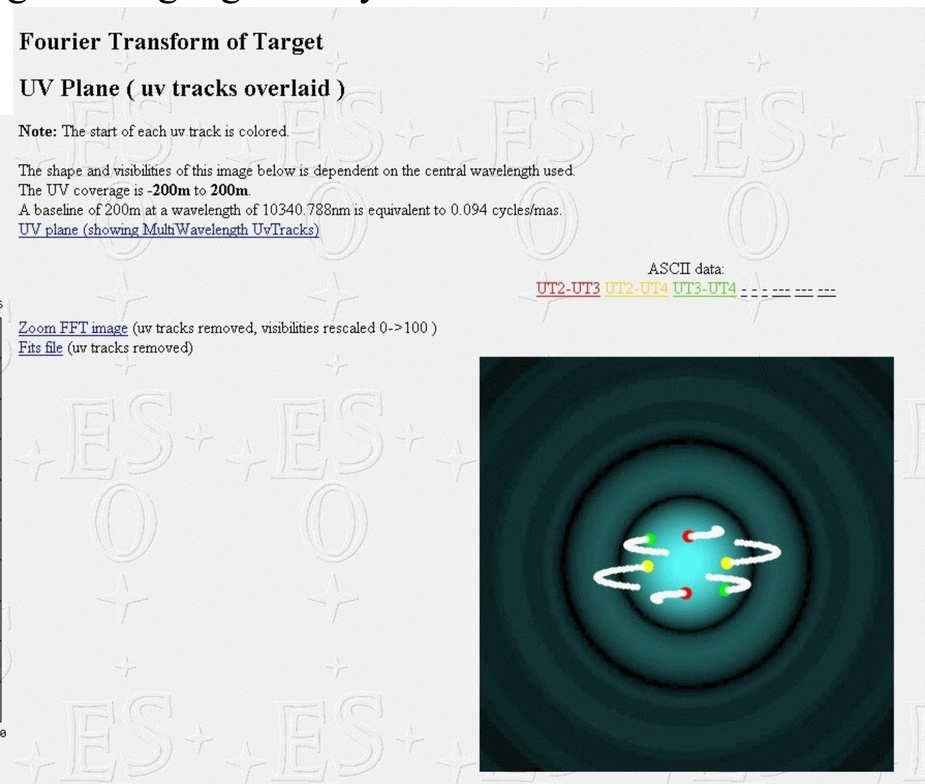
- The scientific goal of an interferometric observing campaign can often only be reached if visibility measurements at different projected baseline lengths and/or angles are combined.

- Each instantaneous visibility measurement requires the submission of one OB. Multiple observations of the same source require the submission of multiple OBs.
- For each OB, the local sidereal time (LST) and the ground baseline has to be specified, as part of the instrument-specific constraint set.
- The pairs of science/calibrator OBs can effectively be considered as stand-alone entities, and are executed independently (for service mode).
- The choice of baselines and LST ranges is supported by the visibility calculator VisCalc.

VLTI Preparation Tools (I) – VisCalc www.eso.org/observing/etc

Calculation of observability and visibility amplitudes for a given target geometry and chosen VLTI configuration.





Declination +7 deg., UD diameter 40 mas, three UT baselines.

Version 3.0.1 released on 24 August 2007.

VLTI Preparation Tools (II) – CalVin www.eso.org/observing/etc

Selection of suitable calibrators from an underlying fixed list based on different user criteria.

List of Calibrators

6 calibrators found

ASCII file format - the first column is the universal time

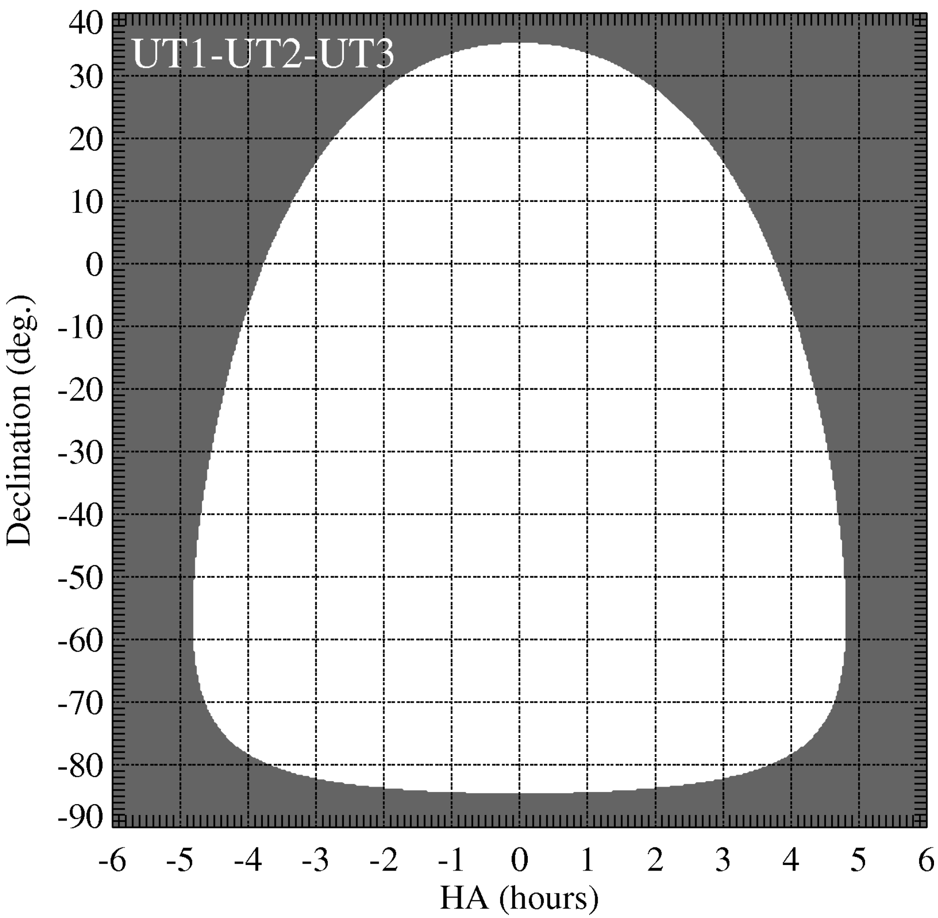
Comparative graphs for "Target" vs. 7 calibrators:- Normalized Visibilities Loss of Correlated Magnitudes Target Altitudes Shadow

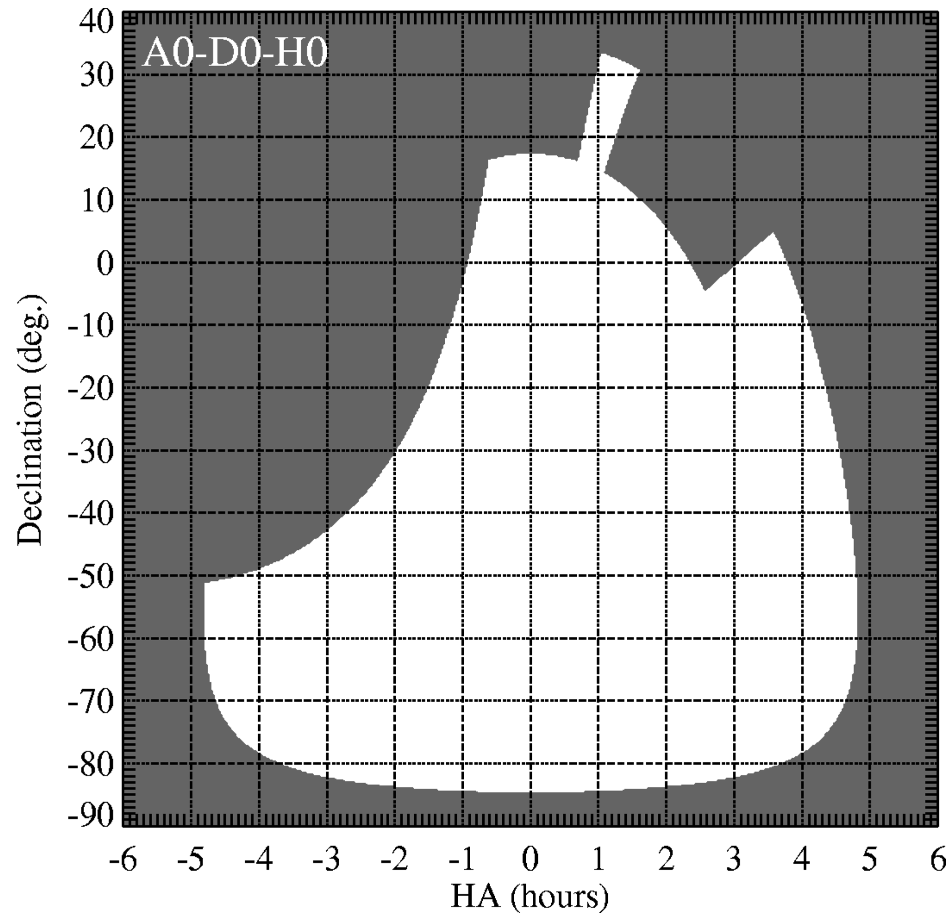
No.	Name	R.A. (h,m,s)	Dec. (d,m,s)	Ang. Dist. (deg°)	Ang. Diam. (mas)	Mag_N	Spec. Type	Lum. Class	Qual. Flag	Normalized Visibility ave ± err range	Loss of Correlated Magnitude ave ± err range	RiseTime SetTime Duration	Culmination MaxAltitude	Shadowing
1 (0)	*Target*	5 55 10.30	7 24 25.40	0.0	40.00 ± 0.00					0.45 ± 0.000 0.30-0.69 graph ascii	1.72 ± -0.00 2.62-0.82 graph ascii	25.25UT 33.75UT 8.50hrs	29.75 UT max = 57° graph ascii	max = 1% graph ascii
2 (195)	hd50778	6 54 11.40	-12 2 19.10	24.4	3.95 ± 0.22	0.67	K4III	III	1	0.99 ± 0.001 0.99-0.99 graph ascii	0.02 ± 0.00 0.02-0.01 graph ascii	25.75UT 33.75UT 8.00hrs	30.75 UT max = 77° graph ascii	max = 0% graph ascii
3 (197)	hd61421	7 39 18.12	5 13 30.00	26.0	5.25 ± 0.21	-0.58	F5IV-V	IV-V	1	0.99 ± 0.001 0.98-0.99 graph ascii	0.03 ± 0.00 0.04-0.01 graph ascii	27.00UT 33.75UT 6.75hrs	31.50 UT max = 60° graph ascii	max = 0% graph ascii
4 (198)	hd48915	6 45 8.92	-16 42 58.00	27.1	6.06 ± 0.13	-1.23	A1	V	1	0.98 ± 0.001 0.98-0.98 graph ascii	0.04 ± 0.00 0.05-0.04 graph ascii	25.50UT 33.75UT 8.25hrs	30.75 UT max = 81° graph ascii	max = 0% graph ascii
5 (192)	hd29503	4 38 10.82	-14 18 14.50	28.9	2.58 ± 0.12	1.30	K1III	III	2	1.00 ± 0.000 1.00-1.00 graph ascii	0.01 ± 0.00 0.01-0.00 graph ascii	23.25UT 33.75UT 10.50hrs	28.50 UT max = 79° graph ascii	max = 1% graph ascii
6 (199)	hd36079	5 28 14.72	-20 45 34.00	28.9	2.97 ± 0.16	0.90	G5II	II	2	1.00 ± 0.001 0.99-1.00 graph ascii	0.01 ± 0.00 0.01-0.01 graph ascii	24.00UT 33.75UT 9.75hrs	29.25 UT max = 85° graph ascii	max = 0% graph ascii
7 (200)	hd65953	8 1 13.33	- 1 23 33.40	32.6	3.05 ± 0.59	1.07	K4III	III	2	1.00 ± 0.002 0.99-1.00 graph ascii	0.01 ± 0.00 0.01-0.01 graph ascii	27.00UT 33.75UT 6.75hrs	32.00 UT max = 66° graph ascii	max = 0% graph ascii

Cal. for Betelgeuse. Angular distance < 35 deg., diameter 0..8 mas, magn 1.3.. -5

Pointing restrictions

Pointing restrictions occur do to the altitude limit (30 deg.), the limited delay line ranges, and shadowing effects.





Date reduction

- AMBER:

Library amdlib, version 2.0, availabe from

http://amber.obs.ujf-grenoble.fr

ESO/Reflex project with AMBER as one prototype

- MIDI:

MIA & EWS software (Jaffe, Koehler, et al.), publicly available at

http://www.strw.leidenuniv.nl/~nevec/MIDI/index.html

Conclusion

- The VLTI with the mid-infrared instrument MIDI and the near-infrared instrument AMBER is offered to the astronomical community for regular service mode and visitor mode observations.
- The same kind and level of support is offered to users of the VLTI instruments as to users of any VLT instrument.
- The complexity of interferometry and the VLTI are hidden to the regular users. Only the main instrument modes and parameters need to be chosen. The observation preparation (OBs) is rather simple compared to some other VLT instruments.
- However, be aware of the complexity of interferometry and the caveats for the analysis and interpretation of the data.