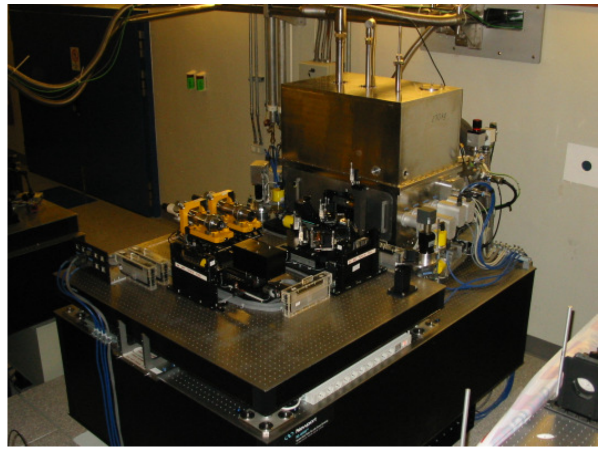
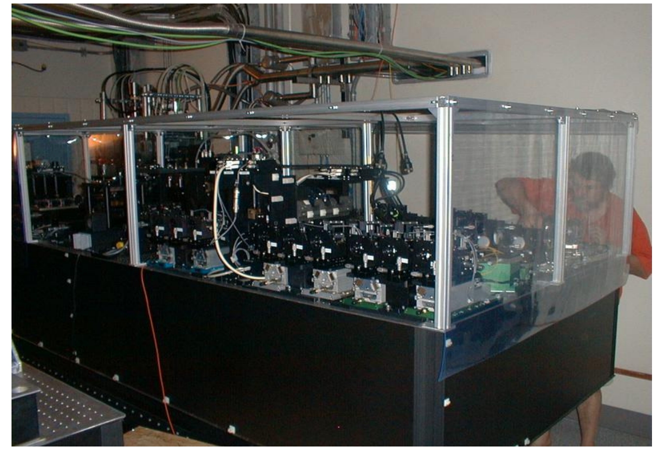
The AMBER & MIDI instruments

Summer School

Astrometry and Imaging with the Very Large Telescope Interferometer

Keszthely, Hungary

2-13 June, 2008

Markus Wittkowski

User Support Department (USD), ESO Garching

11 June 2008

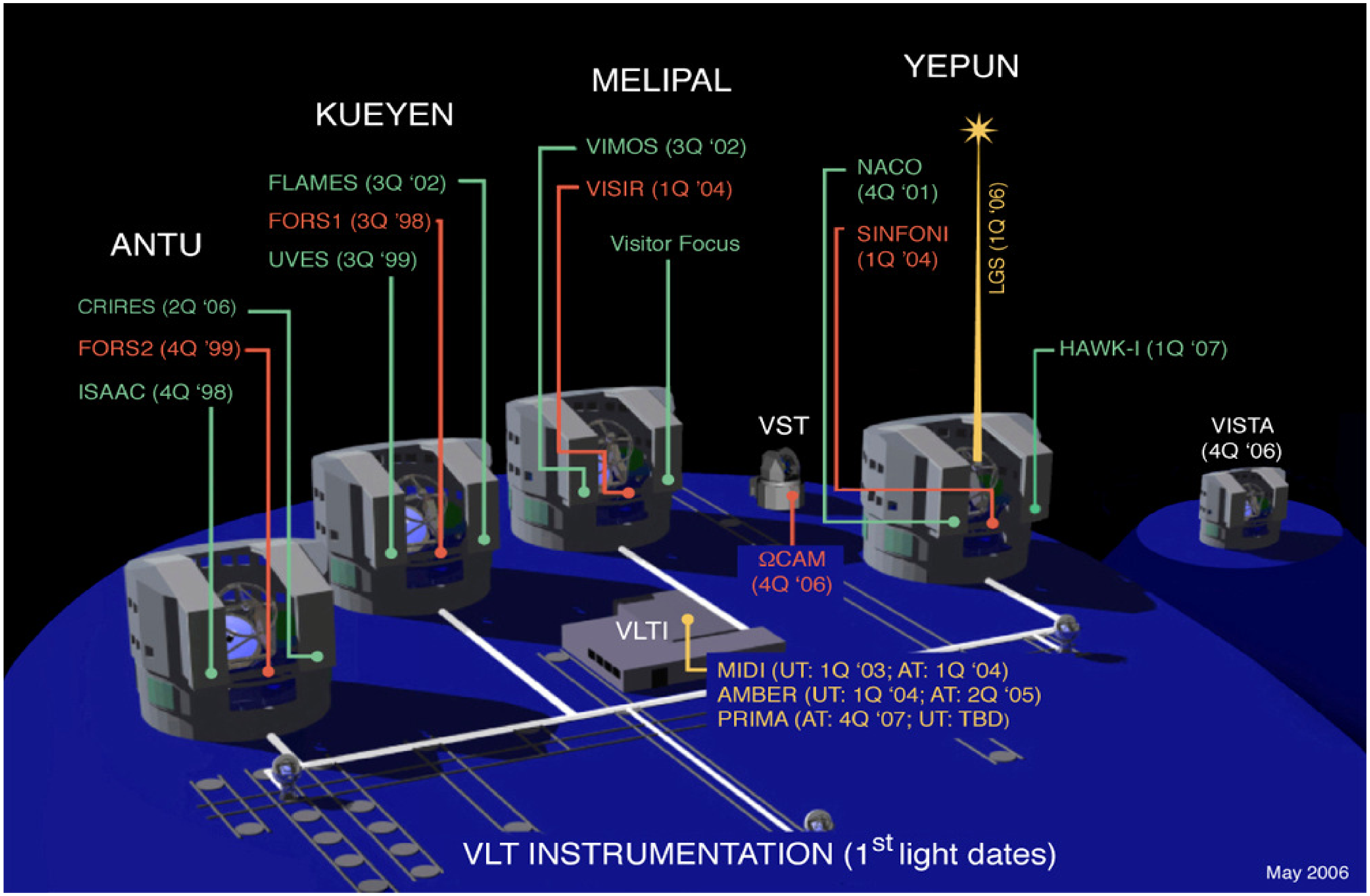
Outline

- Part I: Introductory remarks
- Part I: Technical description of MIDI and AMBER
- Part II: Using MIDI and AMBER (proposal preparation)

Not covered in this lecture:

- The VLTI environment -> Lecture by Markus Schöller
- AMBER/MIDI data reduction -> Lecture and practical session by Christian Hummel

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 μm) 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 μm) 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/sci/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

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

AGB stars: Wittkowski et al. 2008, A&A, 479, L21

- 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, Ohnaka et al. 2008, A&A, 484, 371

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

ESO telescope bibliography

The ESO telescope bibliography lists refereed publications directly based on ESO data: http://archive.eso.org/wdb/wdb/eso/publications/form

As of 5 June 2008:

- 41 publications based on VINCI data
- 42 publications based on MIDI data
- 15 publications based on AMBER data

- 91 publications based on VLTI data
- 54 different first authors (13 with more than 1 first-author VLTI publication)

Have a look at recent papers of the same instrument/instrument mode and of a similar type of objects.

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
P80	Oct 2007 - Mar 2008	FINITO offered for ATs
P82	Oct 2008 - Mar 2009	FINITO offered for UTs

P73-P80:

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.

Technical description of MIDI and AMBER

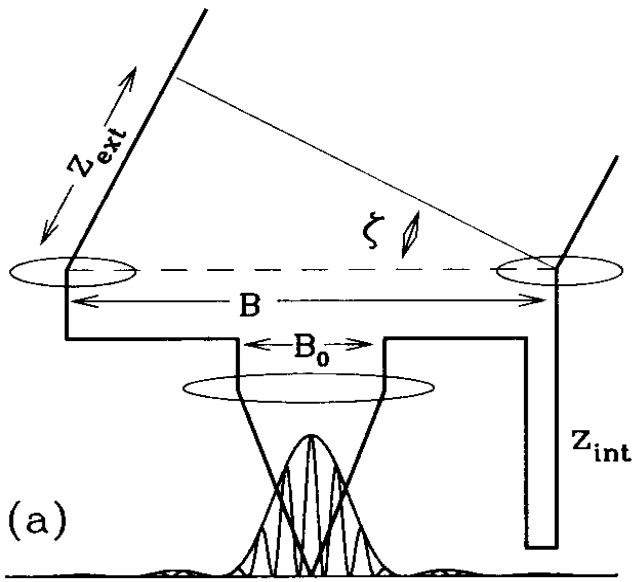
Elements of an interferometric instrument

- Beam combination
- Spatial filtering
- Photometric calibration
- Spectrograph
- Detector

Beam combination

AMBER

Image plane
("Fizeau")

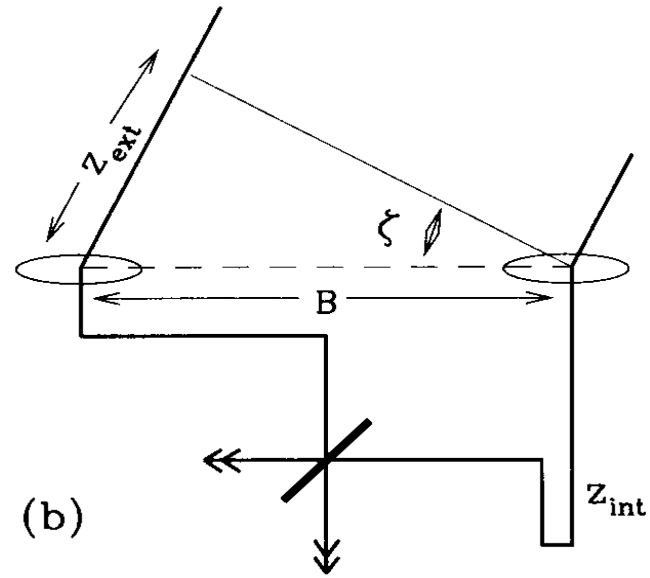


Spatial fringe detection

(geometric delay)

MIDI

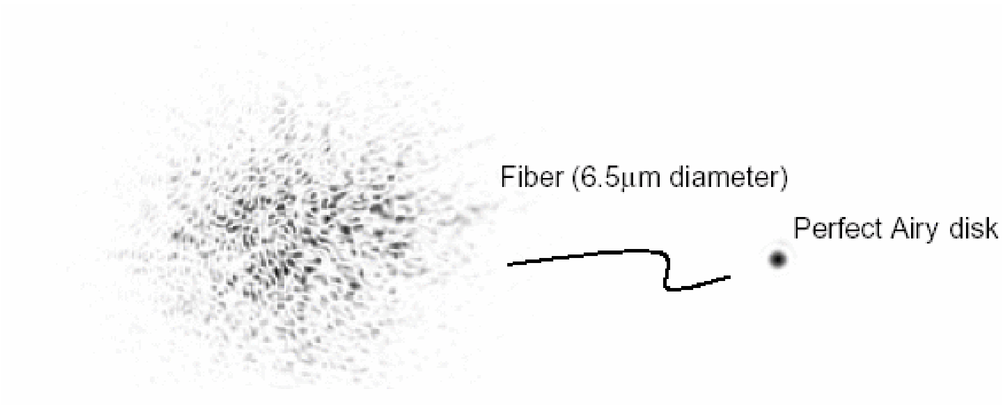
Pupil plane
("Michelson")



Temporal fringe detection

(temporal delay modulation)

Spatial filtering



AMBER

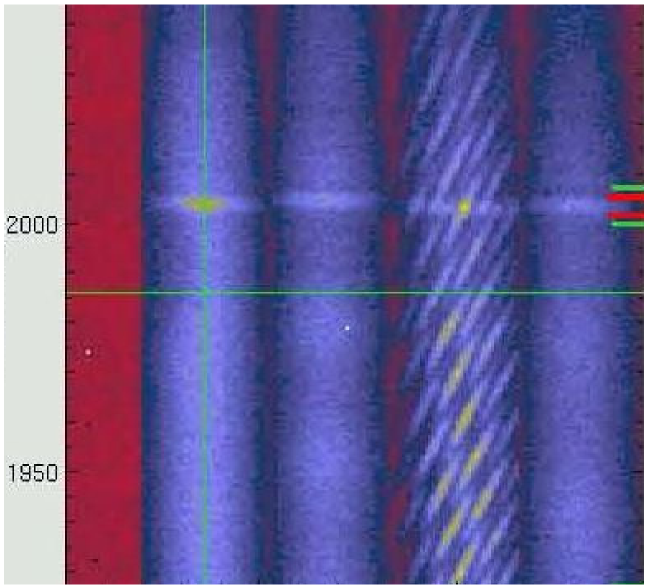
MIDI

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.

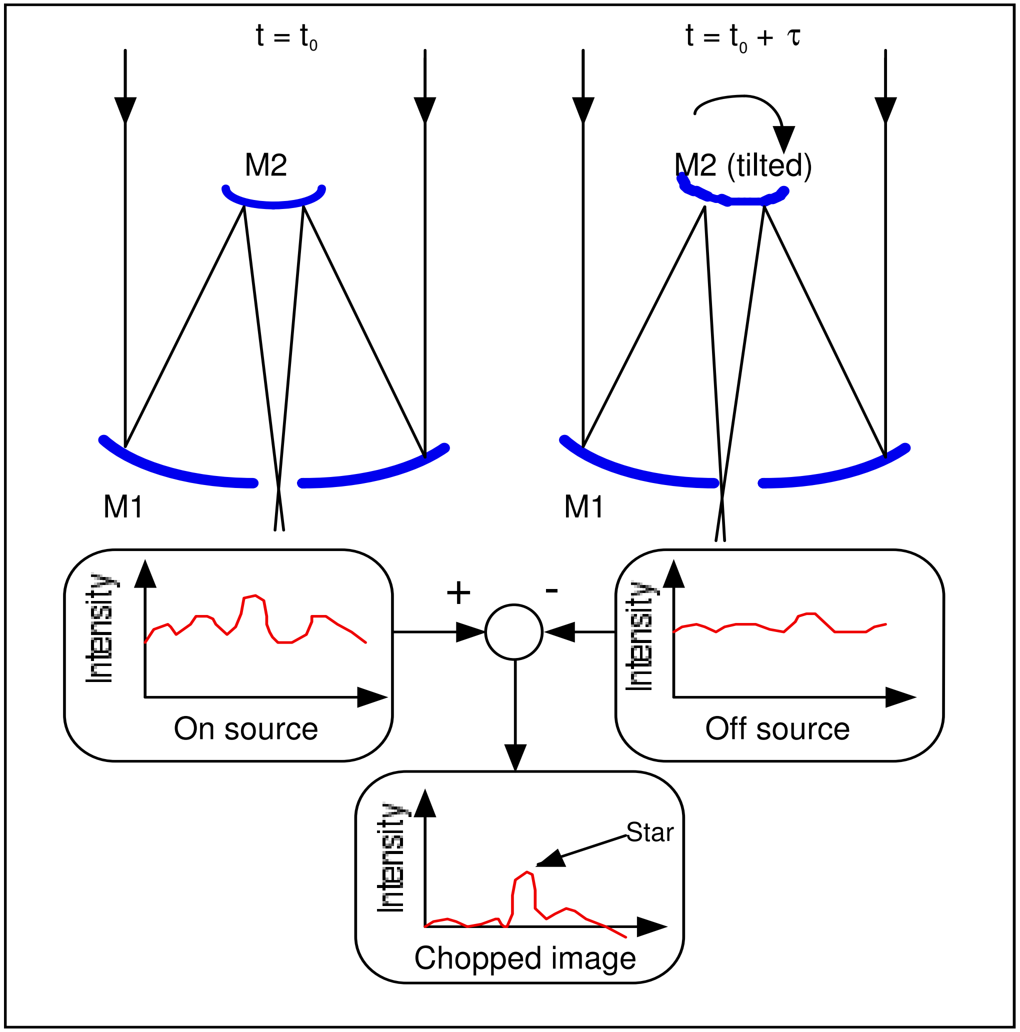
Thermal infrared: CHOPPING for MIDI

- Sky glows with spatial and temporal fluctuations of intensity (H_2O vapor).

- Thermal emission of optics proportional to εT^4

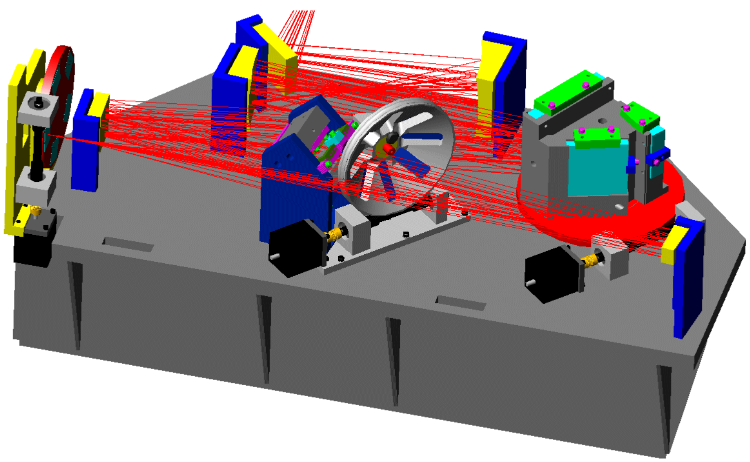
- Mirrors: $\varepsilon \approx 0.05$

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

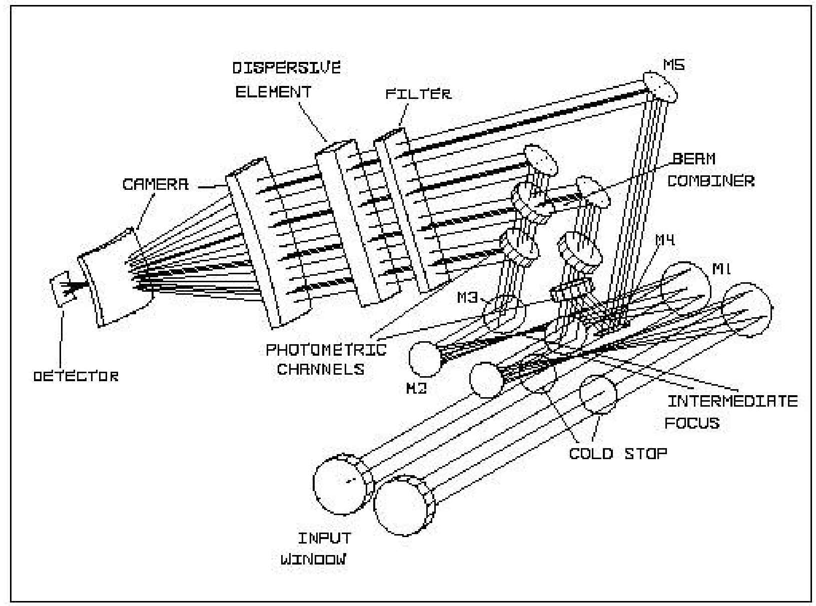


Spectrograph

AMBER



MIDI



Long-slit spectrograph

Prism, LR mode, ●✉☟●~30
MR grism, MR mode, ●✉☟●~1500
HR grism, HR mode, ●✉☟●~12000

Dispersive element:

NaCl prism ●✉☟●~ 30, 1 ●✉D=3px=0.26 a
KRS5 grism ●✉☟●~230, 1 ●/D=2px along y,
1px along x (disp.)

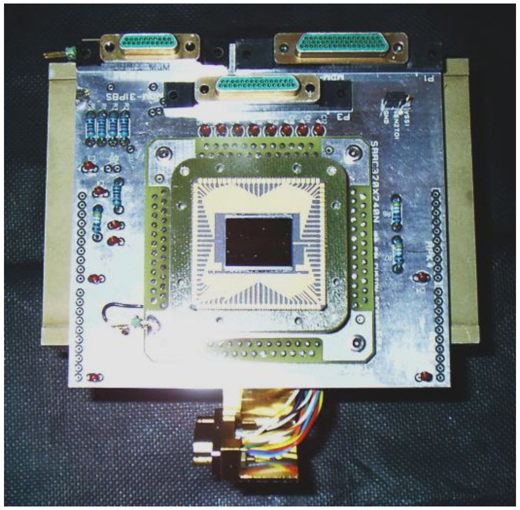
Slit: width 200 ❍m (0.52/2.29 arcsec for UT/AT)
or field interferometry mode

Detector

AMBER

HAWAI I detector,
where only one quadrant is used
512 x 512 px

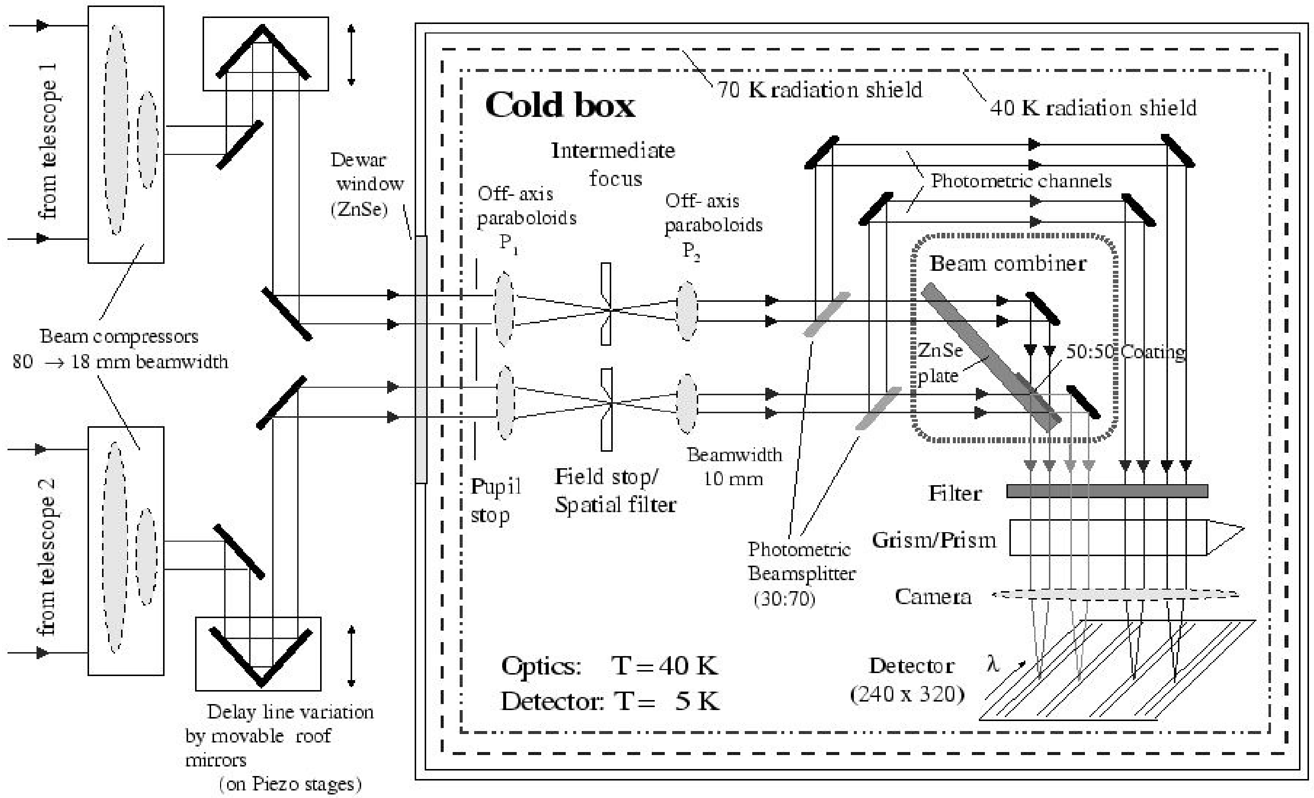
MIDI



320x240 px Raytheon Si:As
Impurity Band Conduction array

Integrate then read mode
Maximum frame rate 160 Hz
Minimum integration time 0.2ms
Windowing
FITS tables

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).

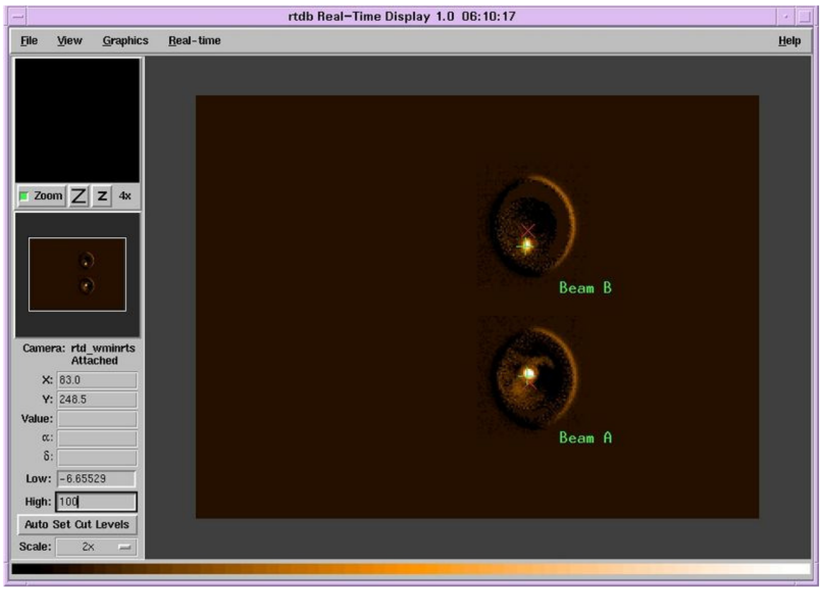
•Beam-combination (pupil plane) by 50/50 beam-splitters.

•Spectral filter. Dispersion by prism or grism.

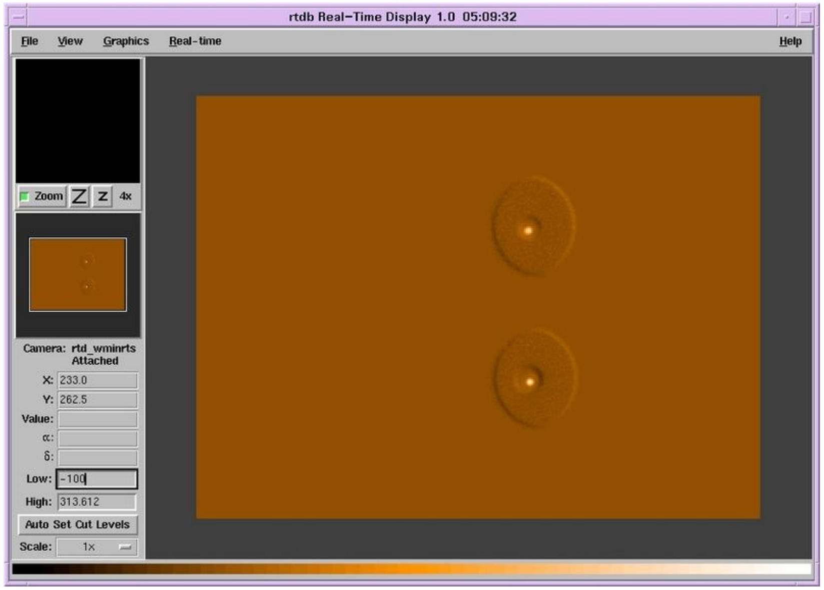
•Focused onto the detector with fast read-out (fringe detection and feedback to delay line).

MIDI: Observation sequence

1. Pointing: Telescope pointing, delay line pointing, Coude guiding (MACAO or STRAP; use of off-axis guide star if required).
2. Adjust the beam overlap (using tip-tilt system IRIS)



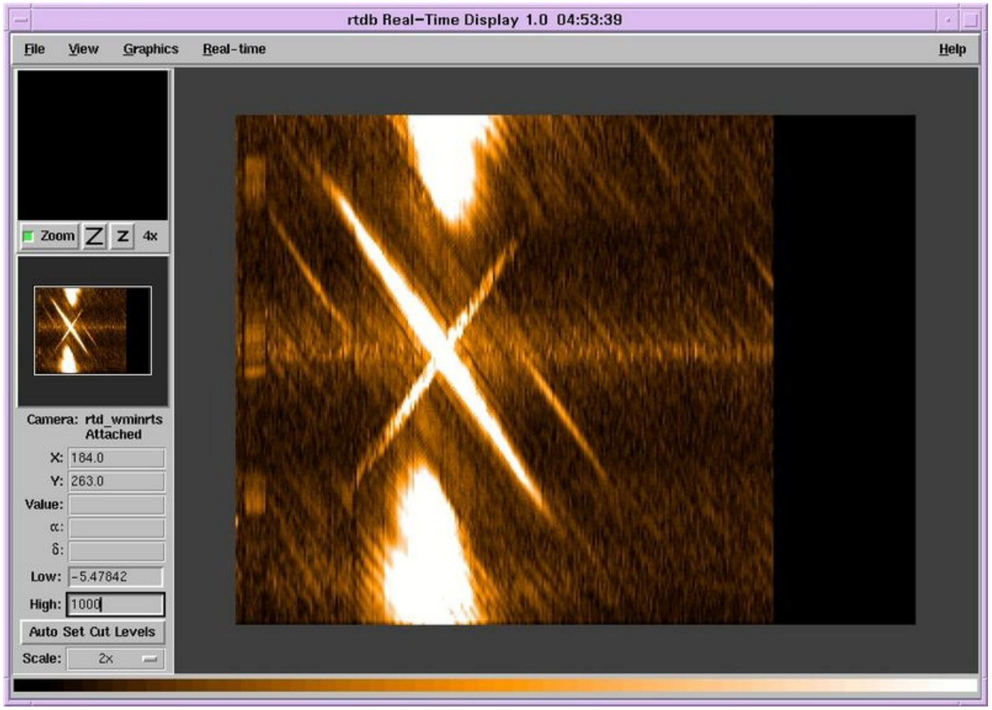
MIDI real time display during the acquisition with the UTs.



MIDI real time display during the acquisition with the ATs.

MIDI: Observation sequence

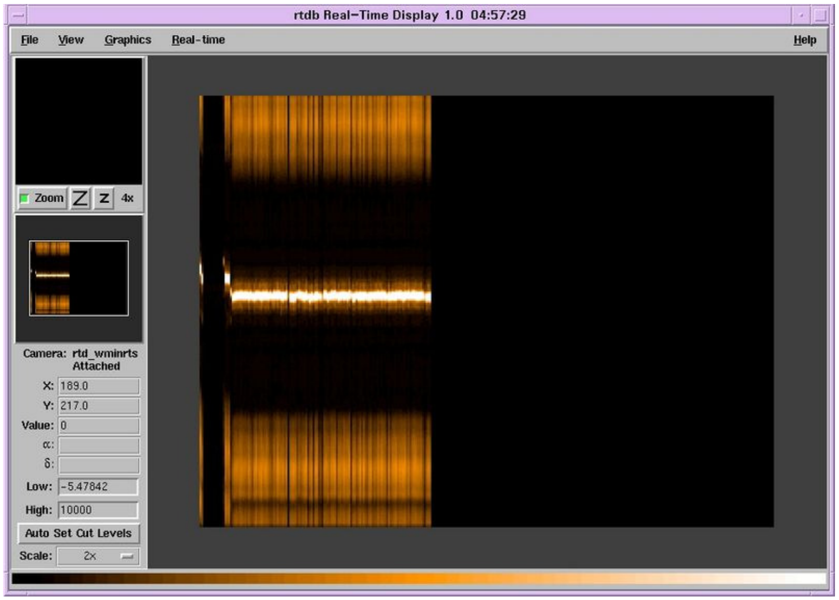
3 Looking for fringes: Search the optical path length offset of the tracking delay .

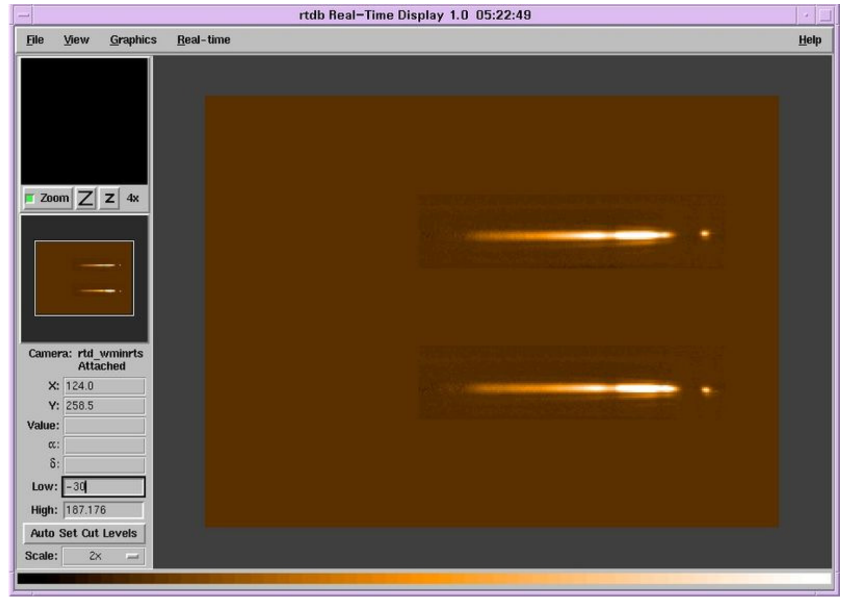


MIDI real time display during the fringe search.
Each vertical line is the fourier transform of a scan. The x-axis is time, or different scans with different optical path difference.

MIDI: Observation sequence

4 Record data.

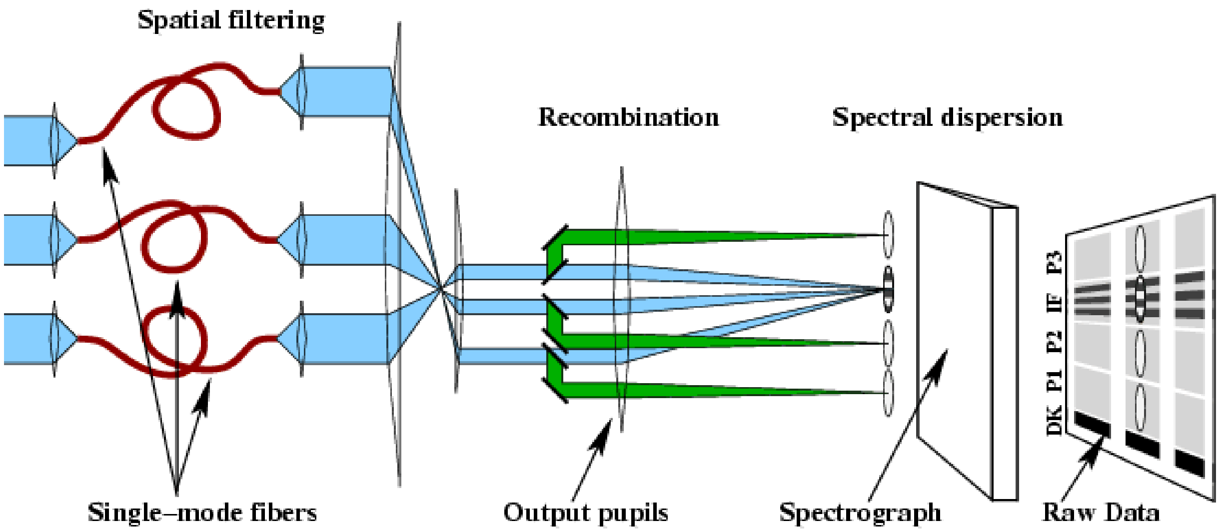


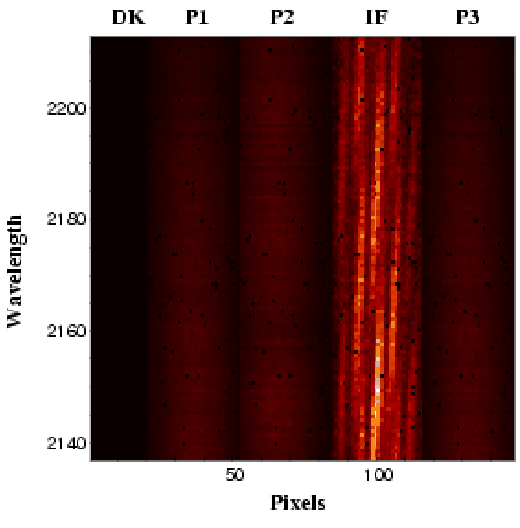


MIDI real time display during the fringe exposure (left) and during the photometry exposure (right).

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.

AMBER: Observation sequence

1. Pointing: Telescope pointing, delay line pointing, Coude guiding (MACAO or STRAP; use of off-axis guide star if required). Setup of the desired spectral resolution, wavelegth range, and DIT. Internal calibration of the chosen instrument configuration (P2VM -> Christian’s lecture)
2. Image optimization using IRIS. Injection adjustment.
3. Fringe search: Search the optical path length offset of the tracking delay lines yielding fringes on AMBER by OPD scans of different offsets. If FINITO is used, this part is done by FINITO.
4. Record data (dark exposures, fringe exposures, sky exposures)

Overview of MIDI and AMBER

	MIDI	AMBER
Beams	2	3
Beam combination	Pupil plane	Image plane
Wavelength	8-13 μm	1-2.5 μm
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)

Using MIDI and AMBER

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.

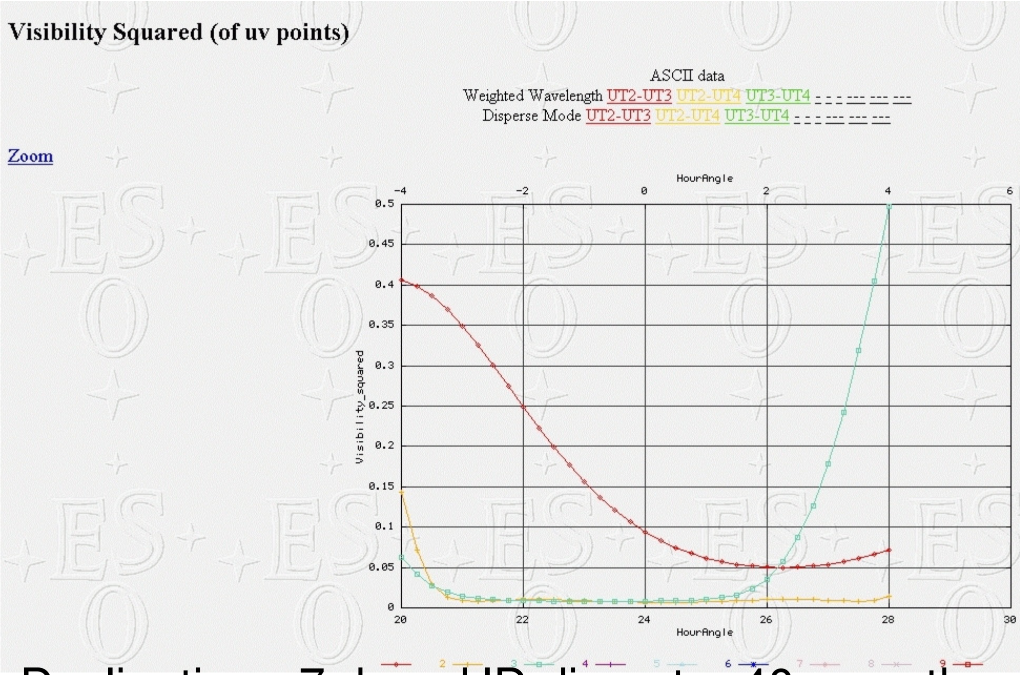
Specific Requirements for Interferometry (II): Combination of different baselines (aperture synthesis)

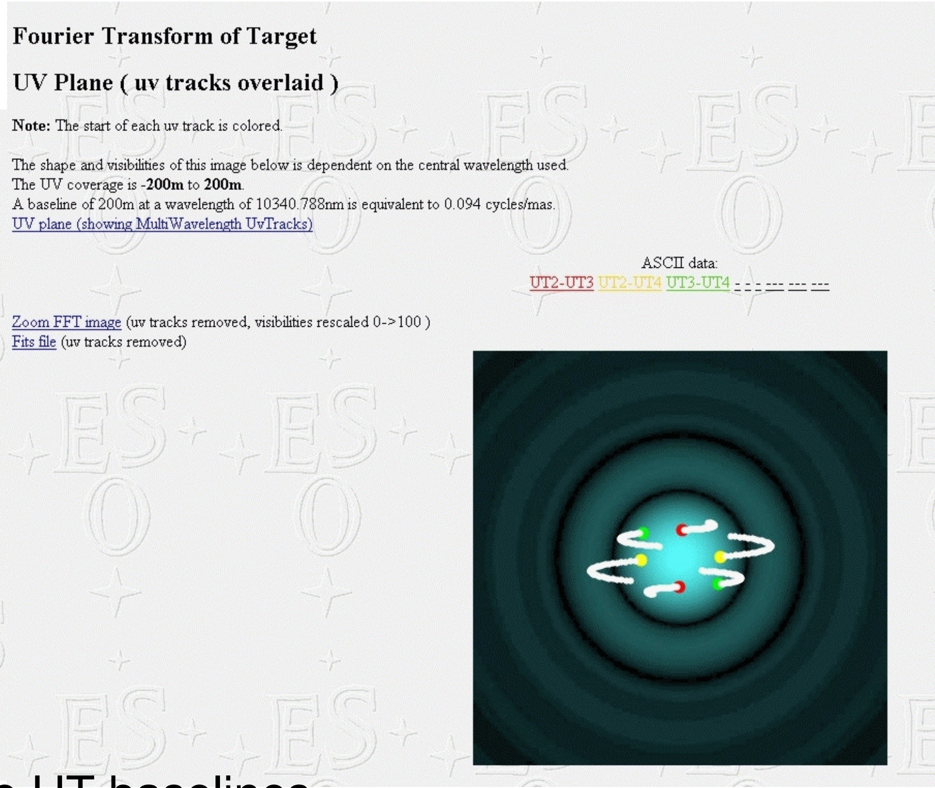
- The scientific goal of an interferometric observing campaign can often only be reached if visibility measurements at different projected baseline lengths and/or angles are combined.

- 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

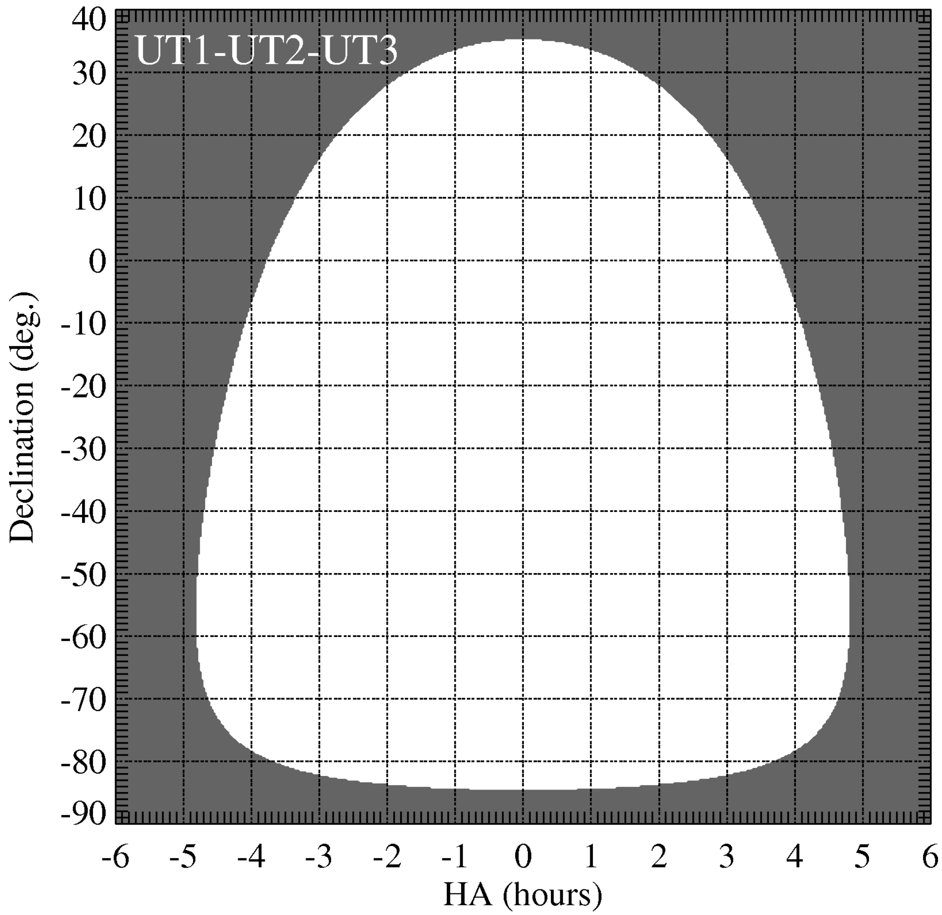
Comparative graphs for *"Target"* vs. 7 calibrators:- Normalized Visibilities Loss of Correlated Magnitudes Target Altitudes Shadow

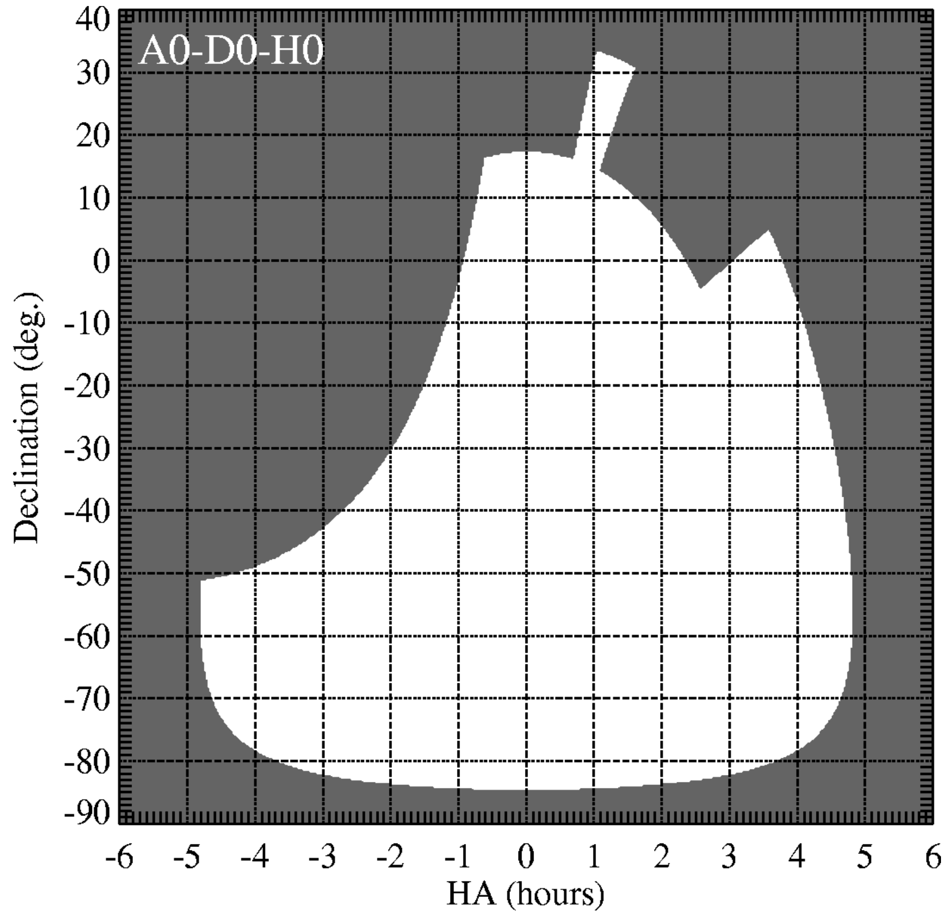
No.	Name	R.A. (h,m,s)	Dec. (d,m,s)	Ang. Dist. (deg°)	Ang. Diam. (mas)	Mag_N	Spec. Type	Lum. Class	Qual. Flag	Normalized Visibility ave ± err range	Loss of Correlated Magnitude ave ± err range	RiseTime SetTime Duration	Culmination MaxAltitude	Shadowing
1 (0)	*"Target"*	5 55 10.30	7 24 25.40	0.0	40.00 ± 0.00					0.45 ± 0.000 0.30-0.69 graph asci	1.72 ± -0.00 2.62-0.82 graph asci	25.25UT 33.75UT 8.50hrs	29.75 UT max = 57° graph asci	max = 1% graph asci
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 asci	0.02 ± 0.00 0.02-0.01 graph asci	25.75UT 33.75UT 8.00hrs	30.75 UT max = 77° graph asci	max = 0% graph asci
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 asci	0.03 ± 0.00 0.04-0.01 graph asci	27.00UT 33.75UT 6.75hrs	31.50 UT max = 60° graph asci	max = 0% graph asci
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 asci	0.04 ± 0.00 0.05-0.04 graph asci	25.50UT 33.75UT 8.25hrs	30.75 UT max = 81° graph asci	max = 0% graph asci
5 (182)	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 asci	0.01 ± 0.00 0.01-0.00 graph asci	23.25UT 33.75UT 10.50hrs	28.50 UT max = 79° graph asci	max = 1% graph asci
6 (189)	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 asci	0.01 ± 0.00 0.01-0.01 graph asci	24.00UT 33.75UT 9.75hrs	29.25 UT max = 85° graph asci	max = 0% graph asci
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 asci	0.01 ± 0.00 0.01-0.01 graph asci	27.00UT 33.75UT 6.75hrs	32.00 UT max = 66° graph asci	max = 0% graph asci

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. Included in VisCalc output.





Data reduction

- AMBER:

Library amdlib, version 2.1, availabe from
http://amber.obs.ujf-grenoble.fr

- MIDI:

MIA & EWS software (Jaffe, Koehler, et al.), publicly available at
http://www.strw.leidenuniv.nl/~nevec/MIDI/index.html

VLT/VLTI observation scheme

- Call for proposals (typically 1 March & 1 September)

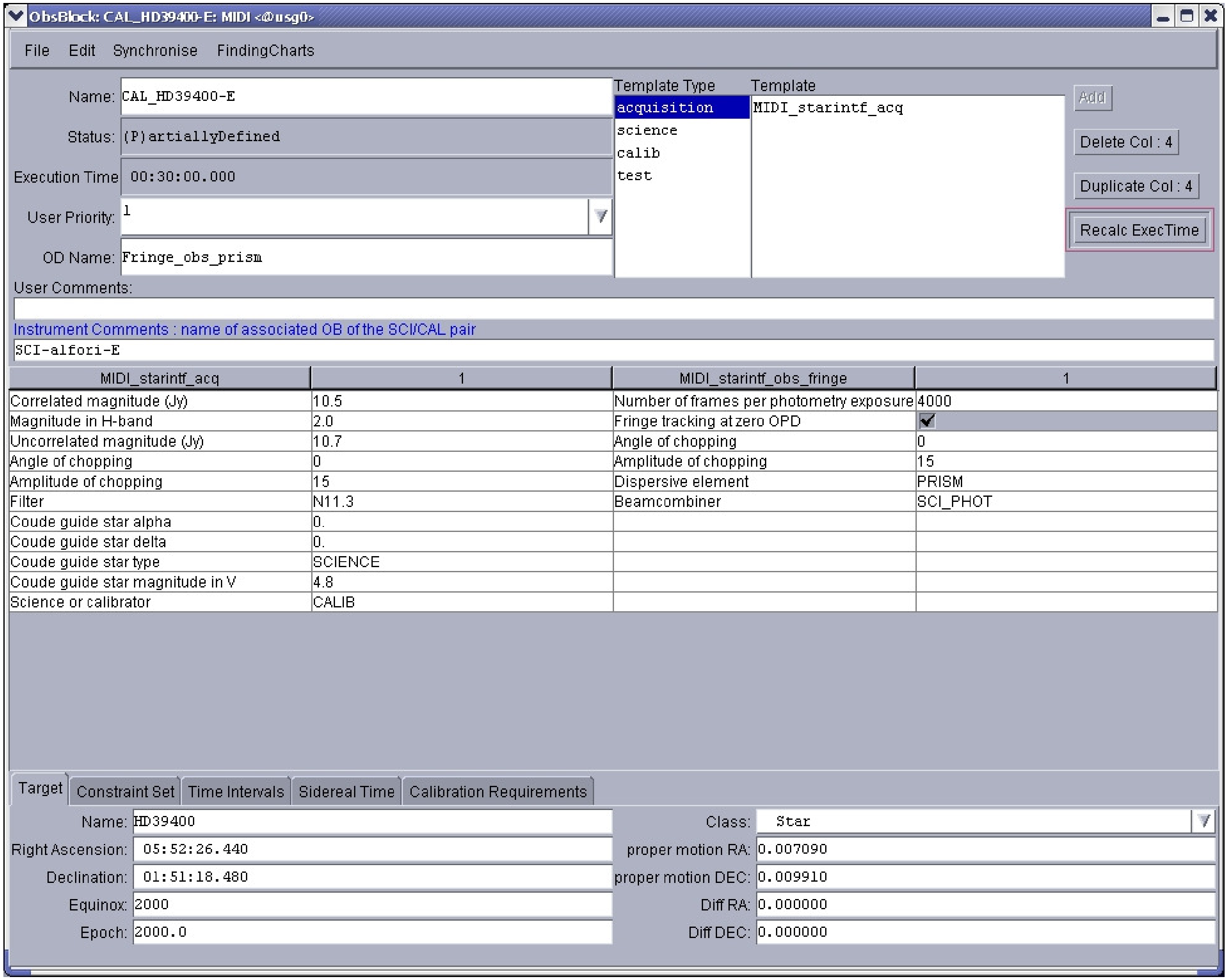
  Announcement of the details of the offered modes and their limits and of the offered baselines/triplets.
- Phase 1 preparation (deadline typically 1 April & 1 October)

  Science case, target selection (bright enough in V, K, N ? good angular size ? accessible with VLTI ?, off-axis guide star needed ?), choice of instrument mode, choice of baseline configuration, cal-sci sequence or cal-sci-cal sequence, number of observations, total time needed, seeing, sky transparency constraints, estimates of visibility and correlated magnitude). Supported by VisCalc.
- Announcement of observing time (end of June/ end of December)
- Phase 2 preparation (typically end June to early August/ end December to early February)

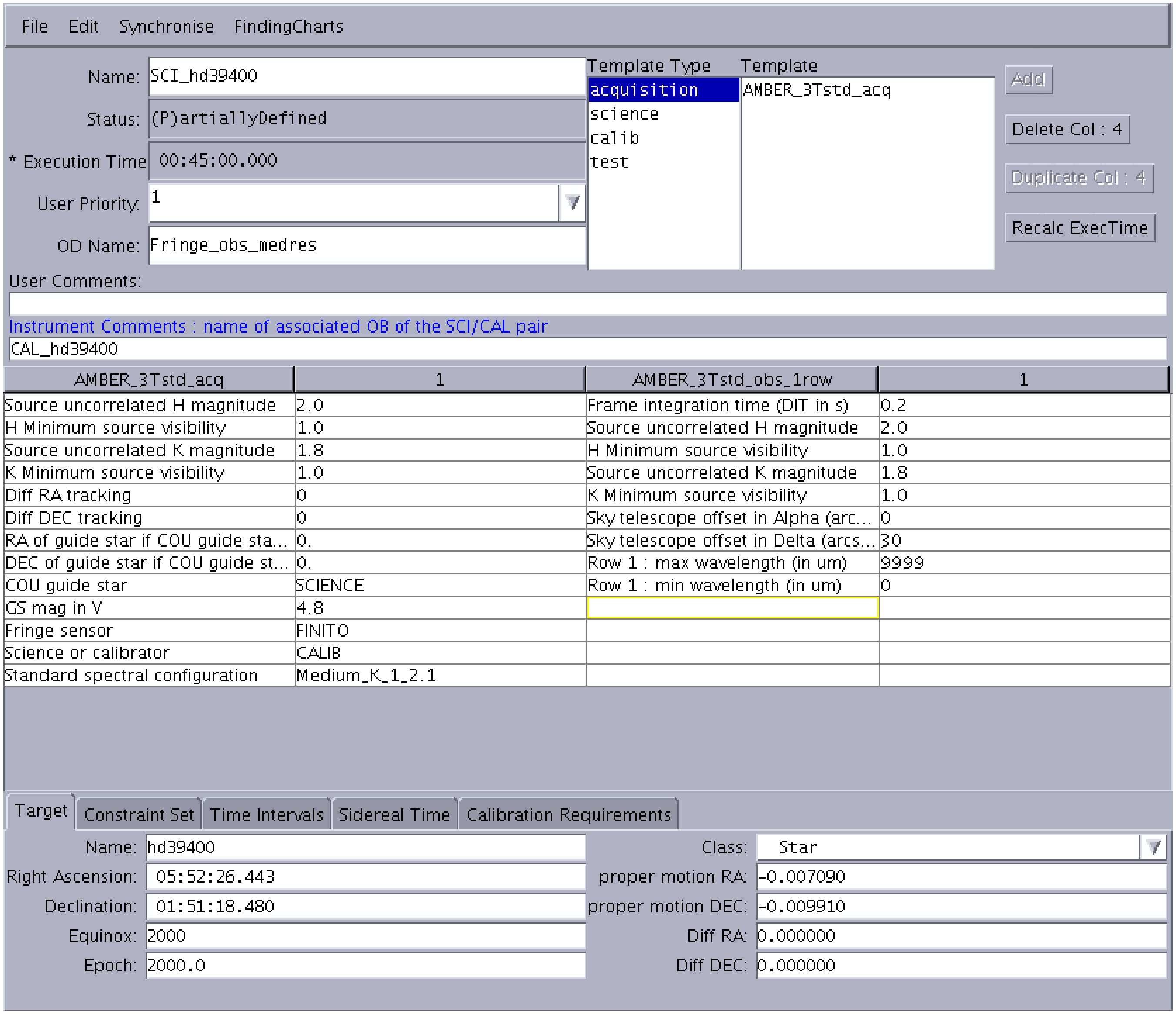
  Detailed preparation of the observation and of the observing blocks to be submitted to ESO. Finding a suitable calibration star. Selection of the LST intervals. Supported by VisCalc and CalVin.
- Observation execution (1 Apr - 30 Sep/ 1 Oct - 31 Mar)

  Check the progress of your program. Look at intermediate data.
- Data delivery

Proposal preparation (Phase 2) - MIDI

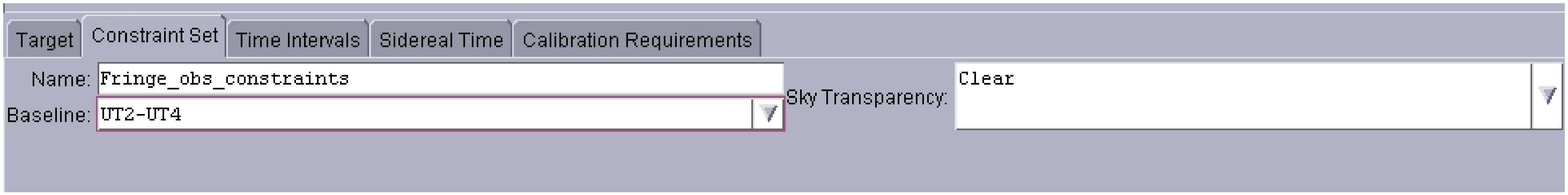


Proposal preparation (Phase 2) - AMBER

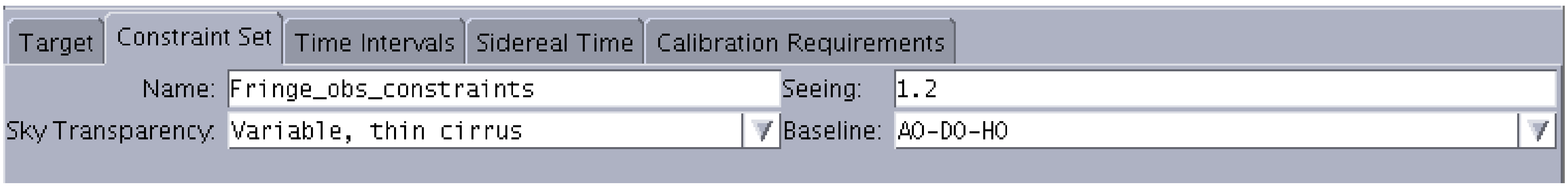


Proposal preparation (Phase 2) – Constraint set

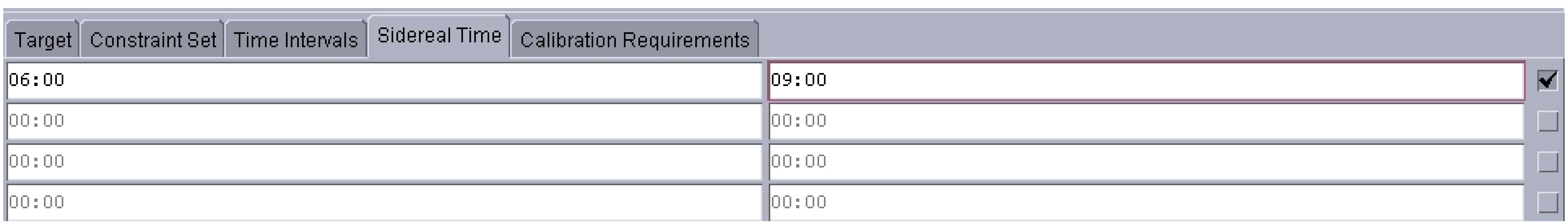
MIDI constraint set:



AMBER constraint set:



LST constraints:



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.