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

Euro Summer School

Circumstellar disks and planets at very high angular resolution

Porto, Portugal

28 May - 8 June, 2007

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31 May 2007

Outline

- The MIDI instrument.
- The AMBER instrument.

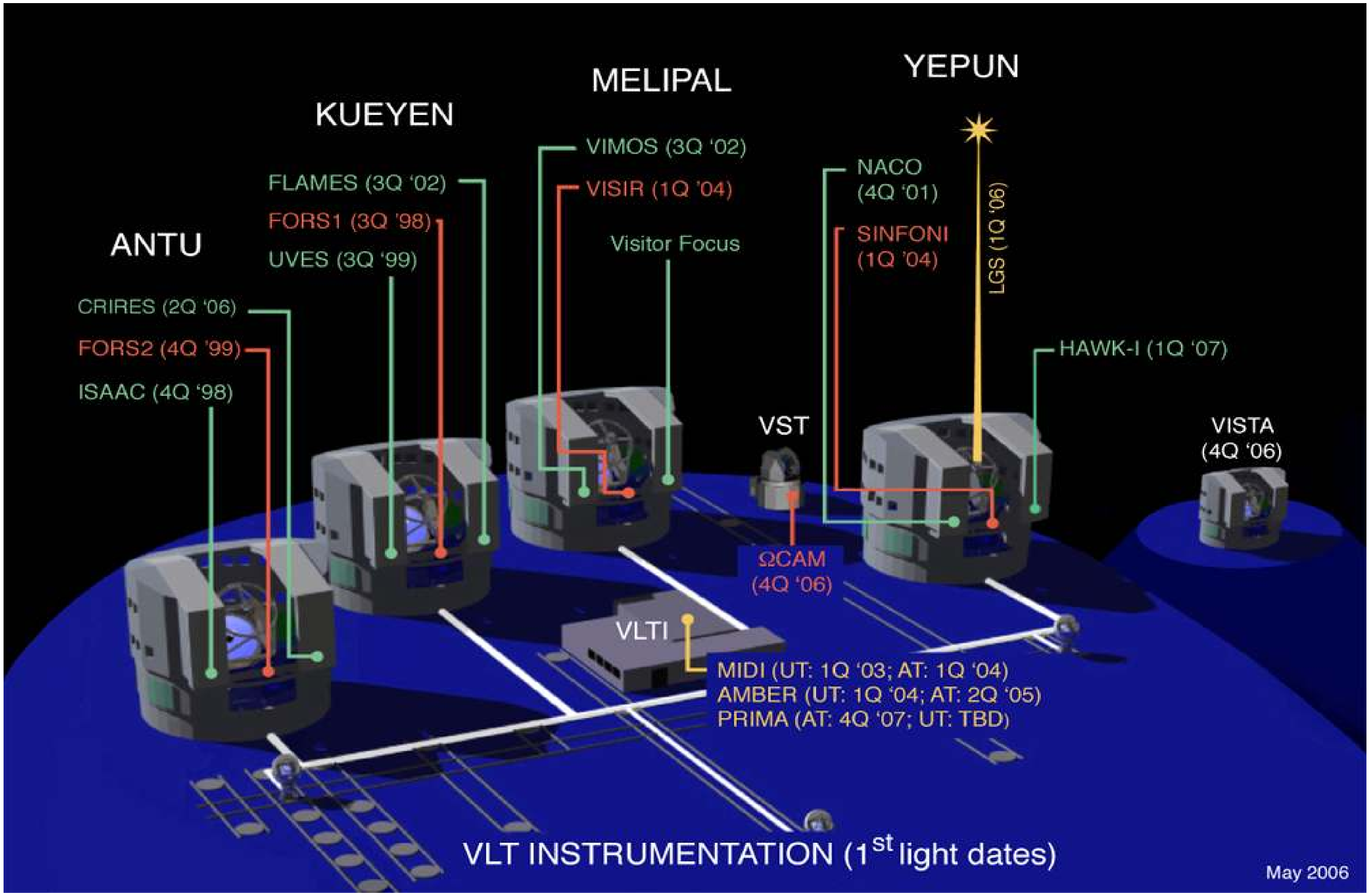
- Observing with the VLTI
- ESO preparation tools VisCalc and CalVin.

Not covered in this lecture:

- Principles of interferometry -> Haniff
- Visibilities, phases, UV space -> Millour, Berger
- The VLTI facility -> Schoeller

- Data from MIDI/AMBER, and visibility estimators -> 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.

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

- 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

- AMBER

Young stellar objects:

Malbet et al. 2007, *Disk and wind interaction in the young stellar object MWC 297 spatially resolved with AMBER/VLTI*, A&A, 464, 43;

Tatulli et al. 2007, *Constraining the wind launching region in Herbig Ae stars: AMBER/VLTI spectroscopy of HD 104237*, A&A, 464, 55

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

Be stars: Domiciano et al. 2007, A&A, 464, 81; 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

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

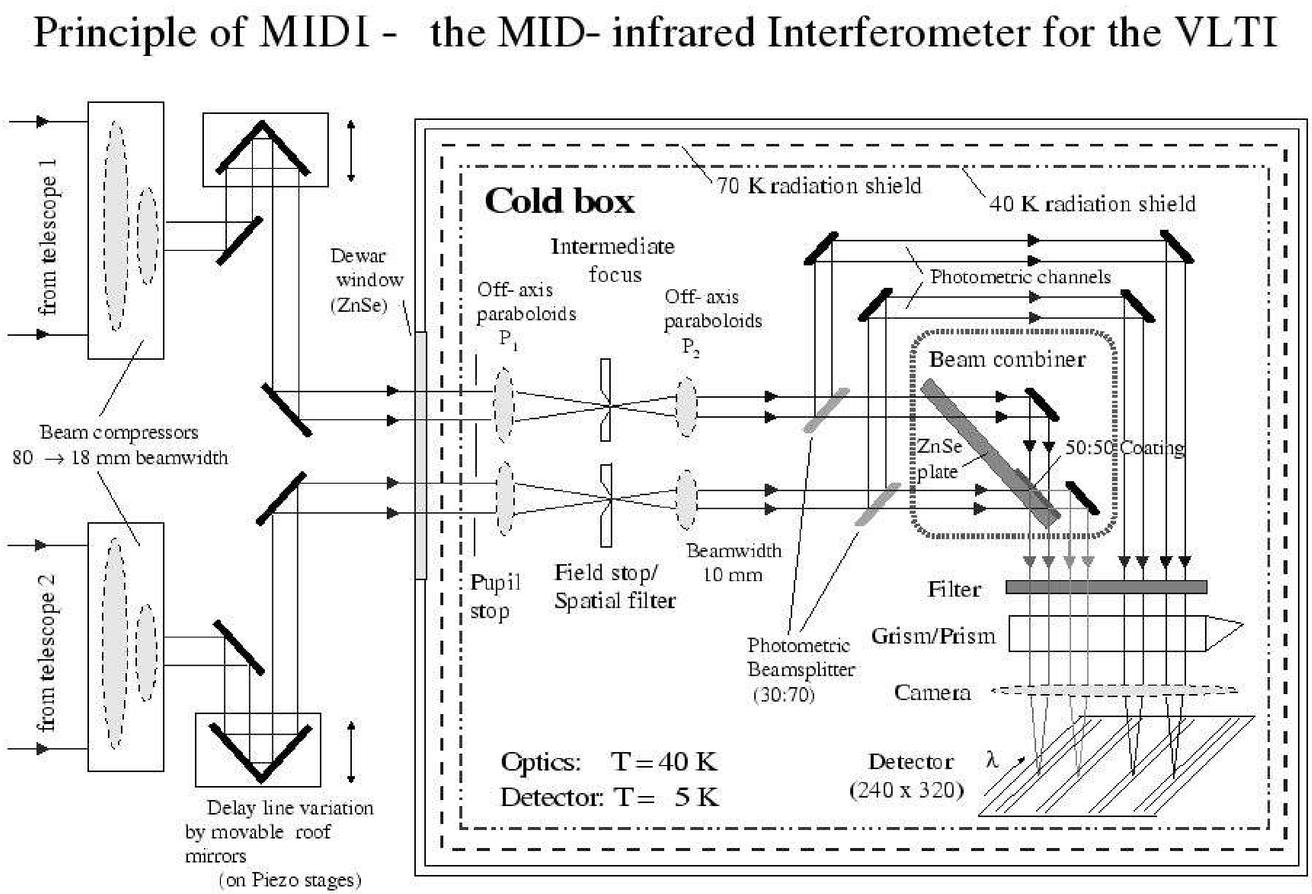
AGB & post-AGB: Ohnaka et al. 2005/2006, A&A 429, 1057/445, 1015; Deroo et al. 2006, A&A, 450, 181; Matsuura et al. 2006, ApJ, 646, L123; Chesneau et al. 2006, A&A, 455, 1009; …

AGN (NGC 1068): Jaffe et al. 2004, Nature 429, 47; Poncelet et al. 2006, A&A, 450, 235

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

Overview of MIDI and AMBER

	MIDI	AMBER
UT First Fringes	December 2002	March 2004
Regular observations	Since April 2004	Since October 2005
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=5.1 (current), FINITO: K<3,H<3 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)
Consortium	D/F/NL (PI Ch. Leinert)	F/D/I (PI R. Petrov)

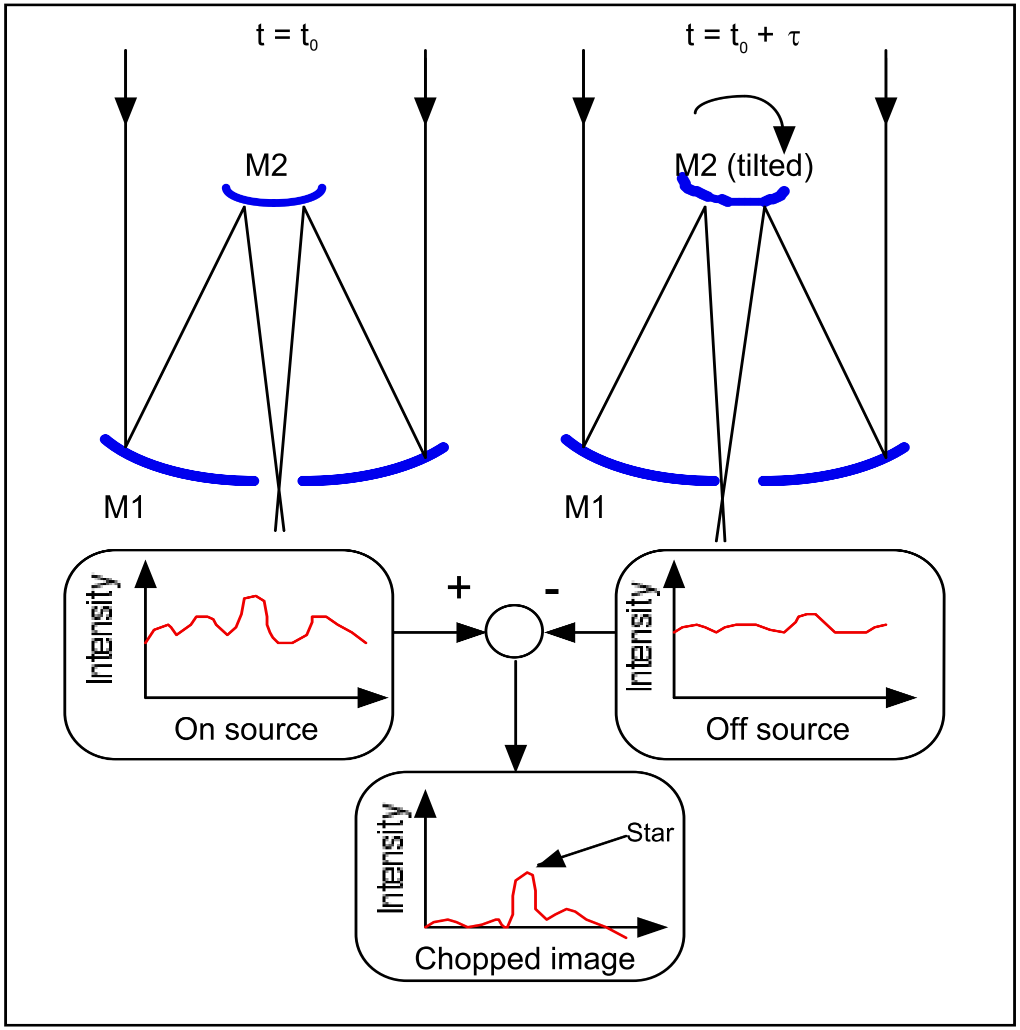


- Light arriving from 2 UTs or 2 ATs, corrected by MACAO or STRAP, IRIS (laboratory tip-tilt), FINITO.
- Time-modulated OPD variations to generate interferograms (warm optics).
- Pupil stops to reduce background and stray-light (cold optics).
- Light focused on field stops (pin-holes for spatial filtering, 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).

CHOPPING for MIDI

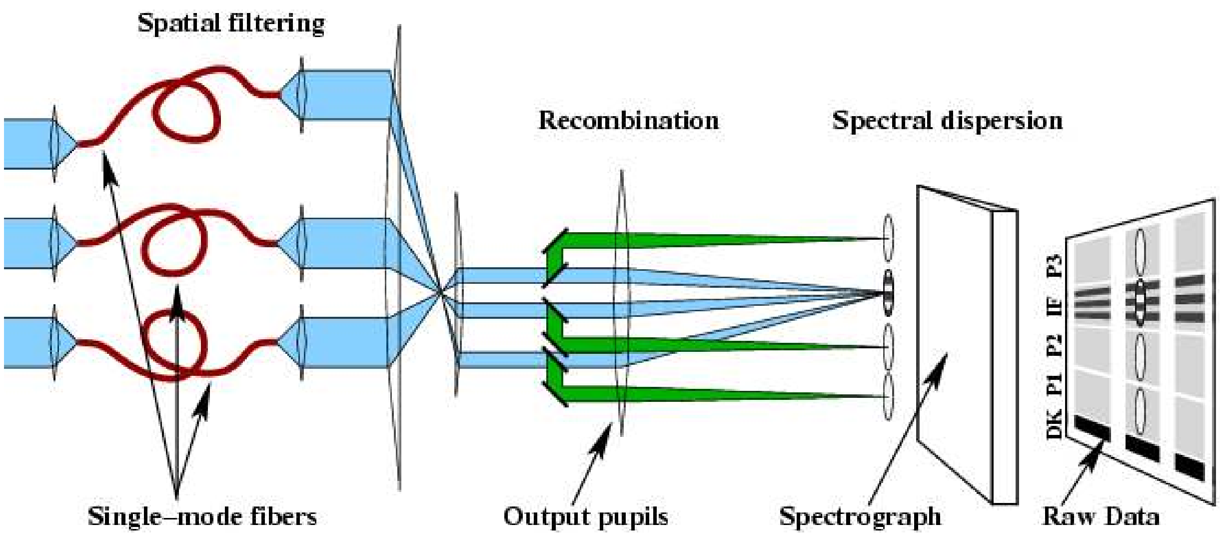
- Sky glows with spatial and temporal fluctuations of intensity (H_2O vapor).
- Thermal emission of optics proportional to εT^4
- Mirrors: $\varepsilon \approx 0.05$

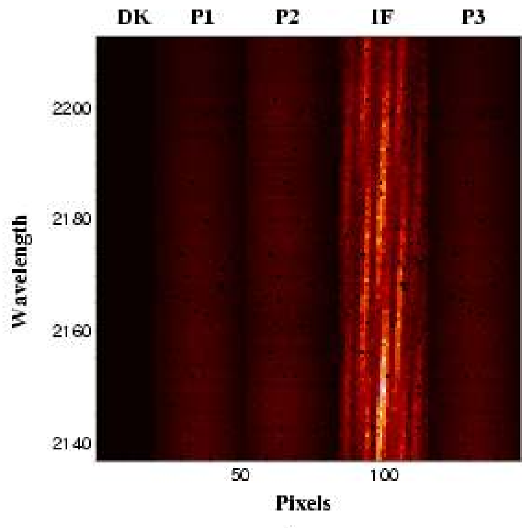
$\Rightarrow$Requirement for chopping for photometric exposures (typically 2 Hz)



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.

Observing with the VLTI

- The VLTI science operations scheme follows and is fully integrated into the regular VLT operations scheme from the initial preparation of the proposal to the delivery of the data.
- In particular, the same kind and level of service and support is offered to users of VLTI instruments as to users of any other VLT instrument.
- All relevant information is provided by ESO through standard documents and via the ESO webpages: Call for proposals, instrument webpages, instrument user manuals and template manuals, general- and instrument-specific proposal and observation preparation instructions.
- Preparation tools: VisCalc (Visibility Calculator) and CalVin (Calibrator Sel.) available from http://www.eso.org/observing/etc.

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 up to P79,
96 AMBER programs, 172 MIDI programs, or 250 VLTI programs
have been scheduled since P73.

49 different AMBER PIs, 67 different MIDI PIs, 101 different VLTI PIs from 11 countries.

The ESO telescope bibliography lists 65 refereed papers directly based on VLTI data, of which 38 papers are based on VINCI data, 23 on MIDI data, and 9 on AMBER data
(as of 25 May 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.

  Under discussion: 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)

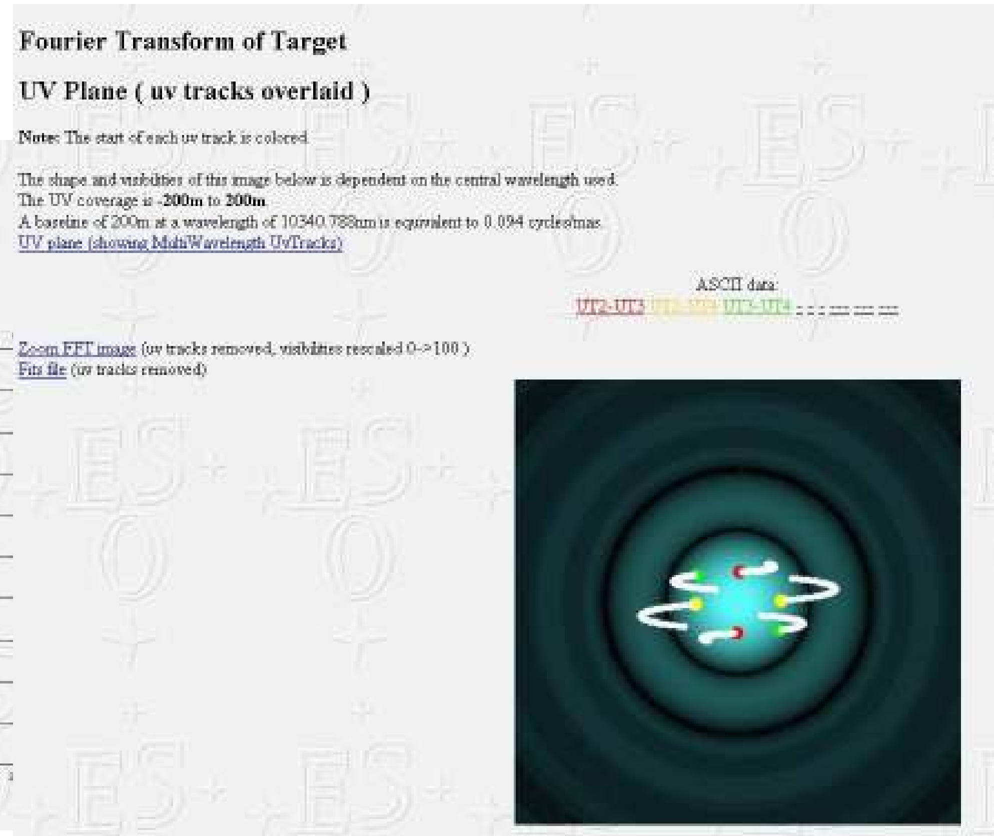
- The scientific goal of an interferometric observing campaign can often only be reached if visibility measurements at different projected baseline lengths and/or angles are combined.

- 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.

  Under discussion: alternative baselines (?)
- 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.

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

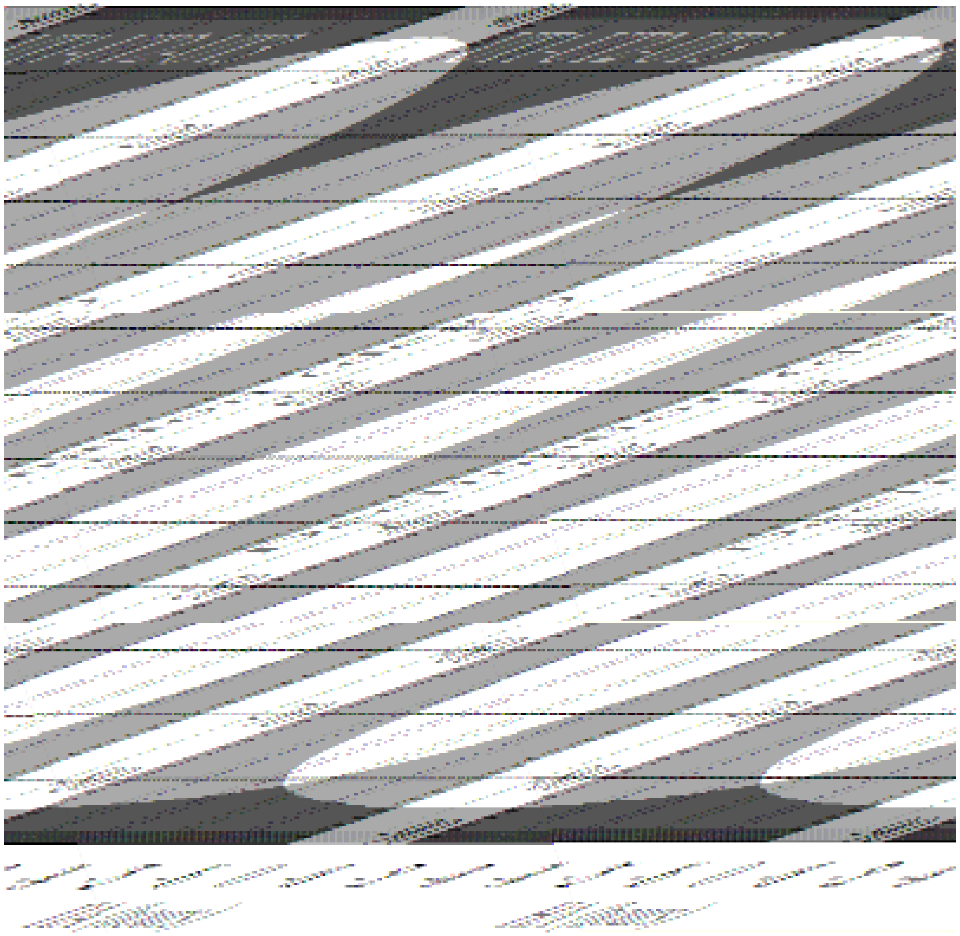
Comparative graphs for "Target" vs. 7 calibrators:- Normalized Visibilities Loss of Correlated Magnitudes Target Altitudes Shadow

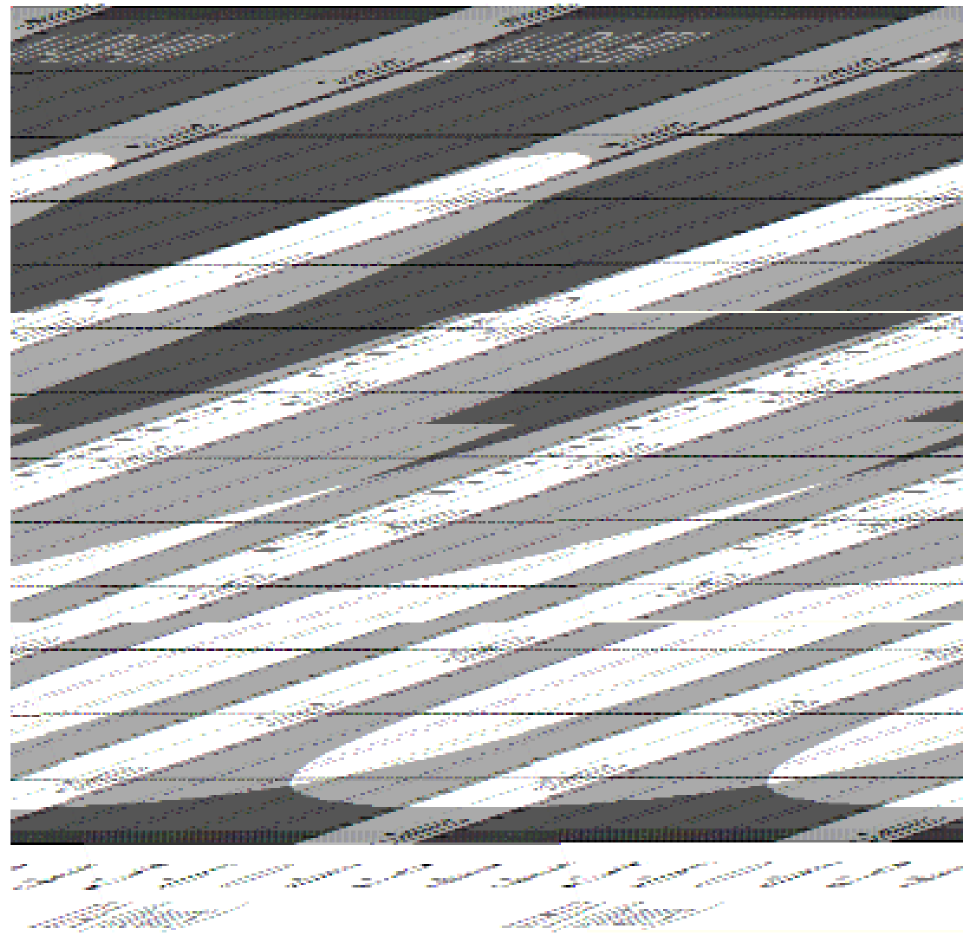
No.	Name	R.A. (h,m,s)	Dec. (d,m,s)	Ang. Dist. (deg°)	Ang. Diam. (mas)	Mag_N	Spec. Type	Lum. Class	Qual. Flag	Normalized Visibility ave ± err range	Loss of Correlated Magnitude ave ± err range	RiseTime SetTime Duration	Culmination MaxAltitude	Shadowing
1 (0)	"Target"	5 55 10.30	7 24 25.40	0.0	40.00 ± 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 (193)	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.





Quality Control and Data delivery

- The fulfillment of the constraint set is checked right after the observation on Parananl.
- The quality of the pipeline-processed data is checked in detail once the data arrive in the archive in Garching.
- Once a run is completed, a data package is sent to the PI. This package contains: The raw data associated to the run including acquisition images from both telescopes, fringe tracking data, photometric data; pipeline-processed data associated to the run; Obtained transfer function for the respective night as obtained by the pipeline-processed data of all calibration stars.
- The raw data of all calibration stars is public and can be requested from the ESO Archive.

Conclusion

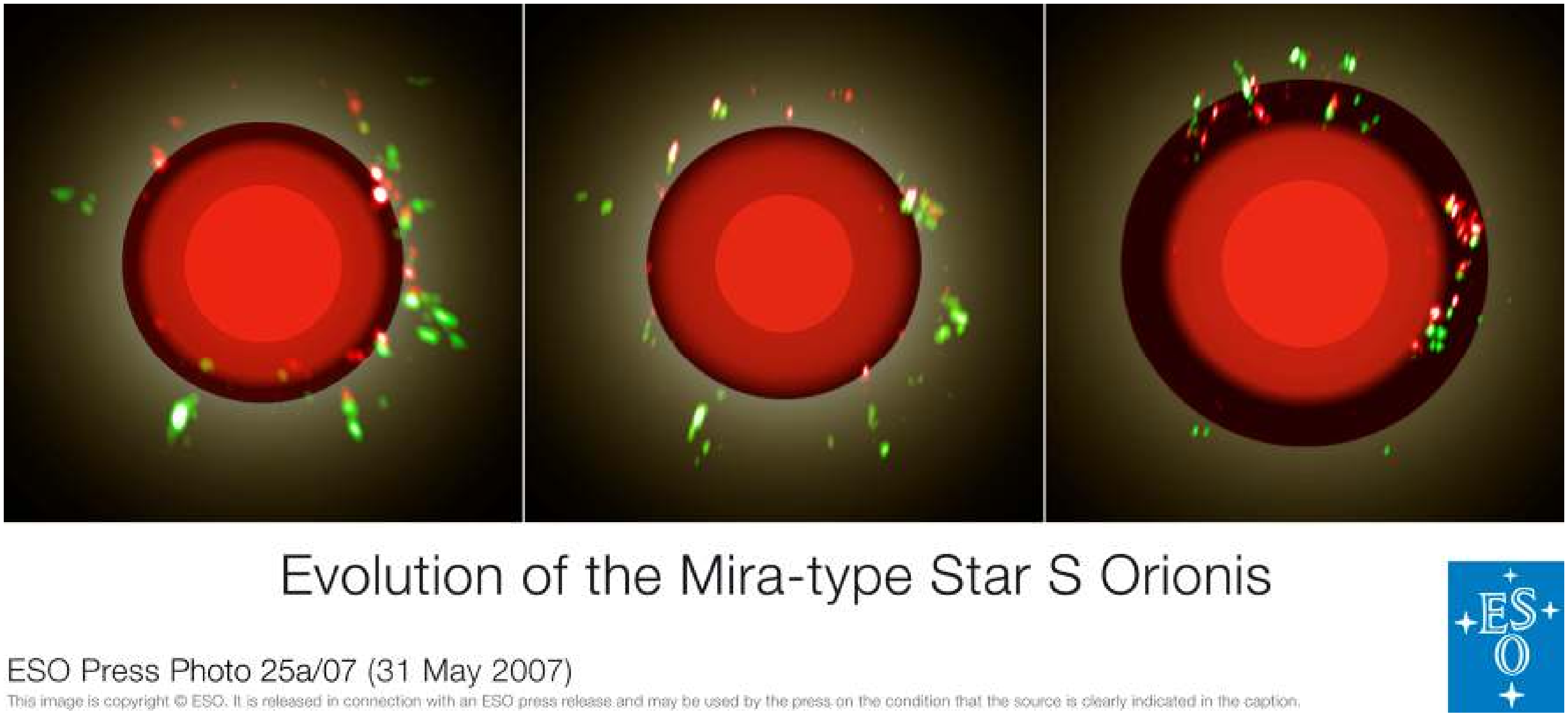
- The VLTI with the mid-infrared instrument MIDI and the near-infrared instrument AMBER is offered to the astronomical community for regular service mode and visitor mode observations.

- 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.

ESO PR 25/07: Chronicle of a Death Foretold



Joint VLTI/VLBA observations of the Mira variable S Orionis at 4 epochs.

http://www.eso.org/public/outreach/press-rel/pr2007/pr-25-07.html