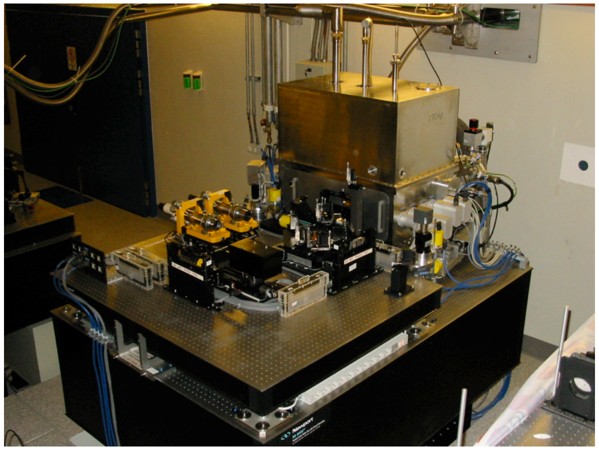
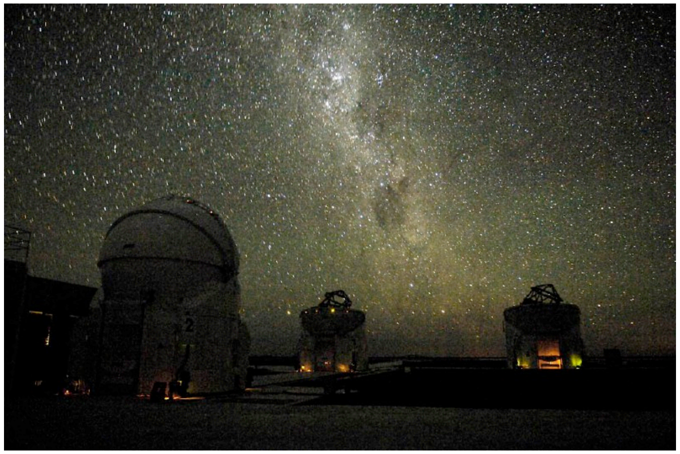
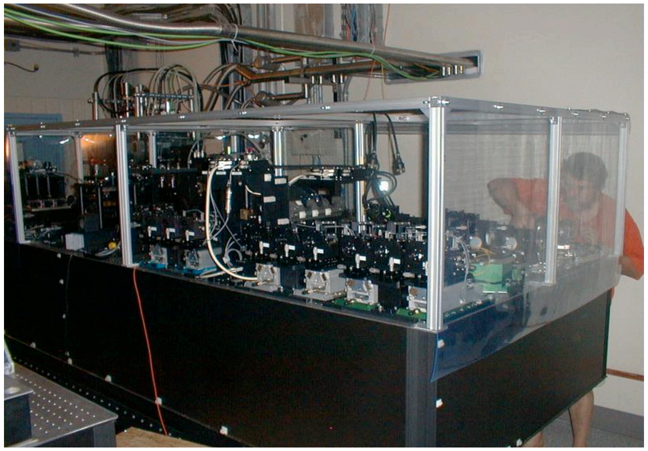
Using the VLT Interferometer AMBER and MIDI instruments





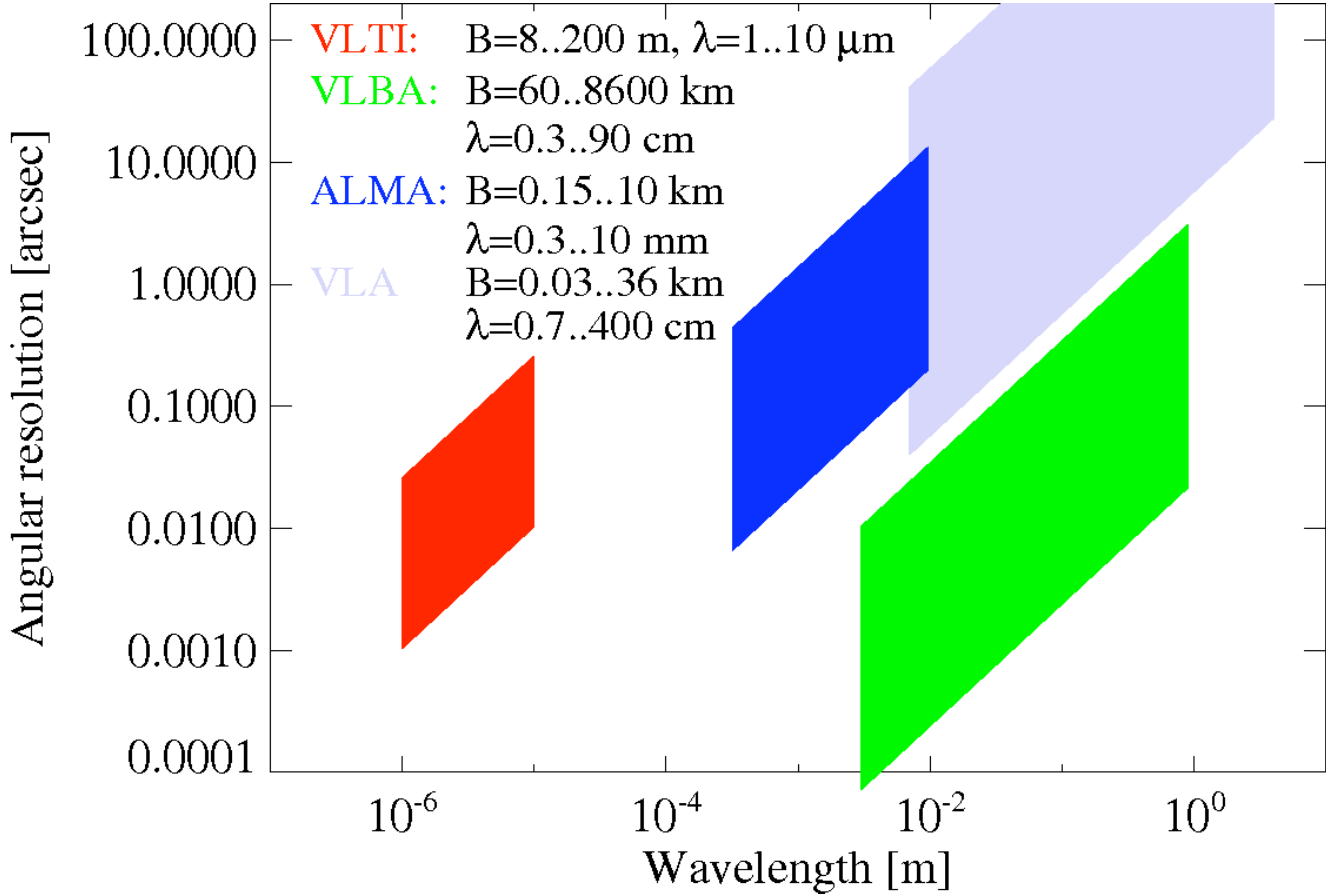


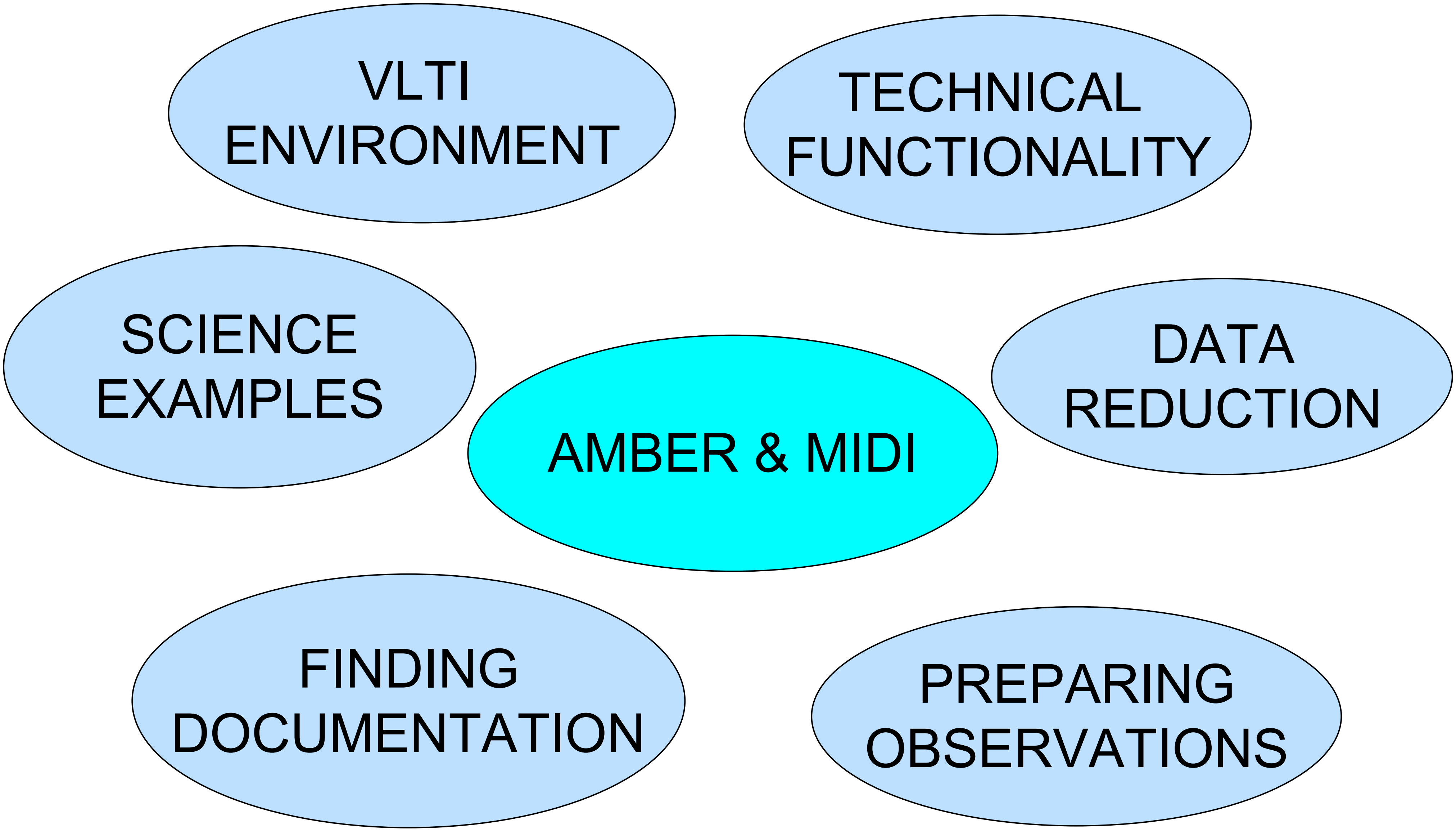
Interferometry Primer

ESO Workshop "Evolution of Solar-mass Stars"

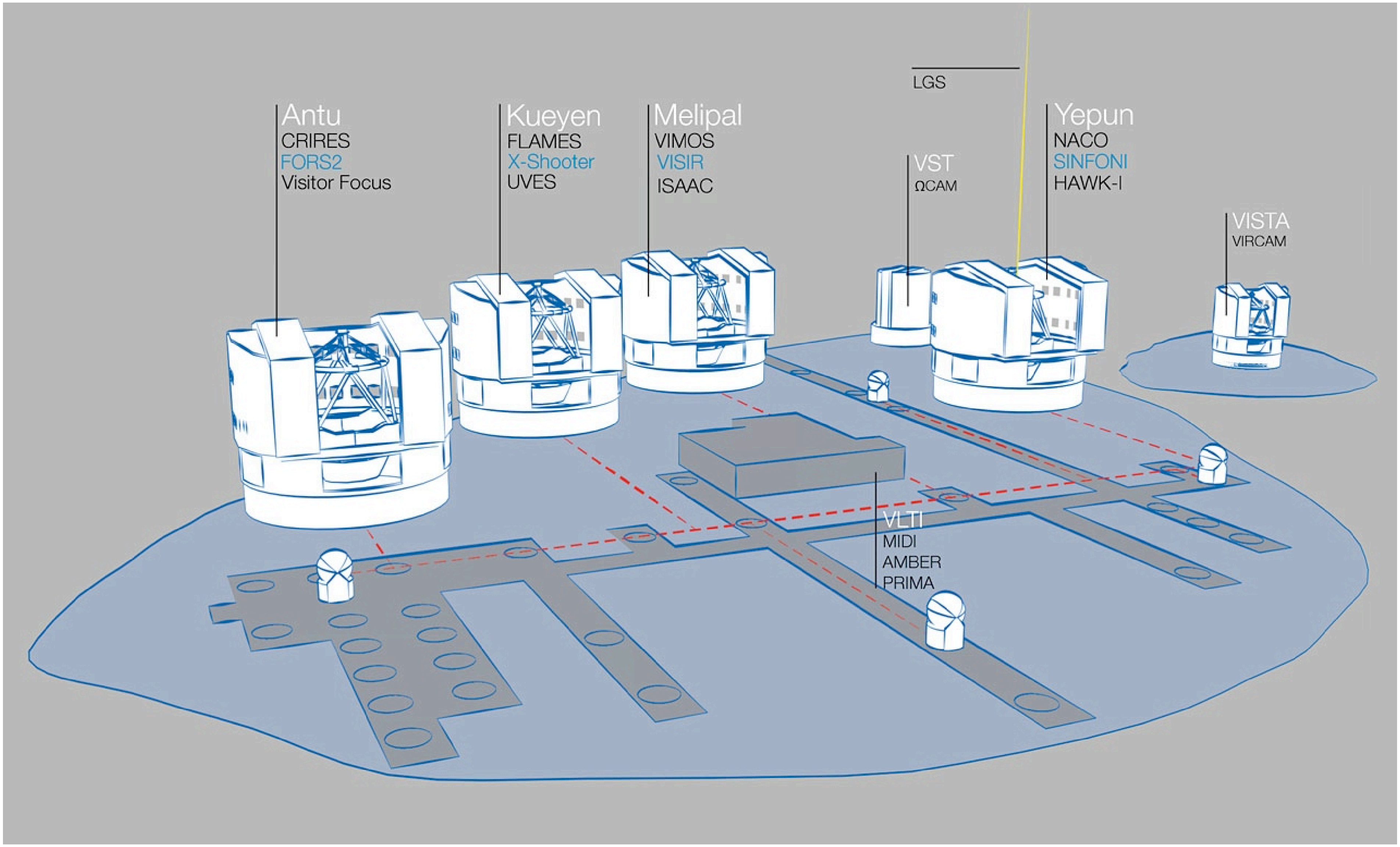
ESO Headquarters Garching
1 March 2010

Markus Wittkowski
User Support Department (USD), ESO Garching


VLTI: B=8..200 m, λ=1..10 μm
VLBA: B=60..8600 km
λ=0.3..90 cm
ALMA: B=0.15..10 km
λ=0.3..10 mm
VLA B=0.03..36 km
λ=0.7..400 cm
Angular resolution [arcsec]
100.0000
10.0000
1.0000
0.1000
0.0100
0.0010
0.0001
10^-6
10^-4
10^-2
10^0
Wavelength [m]


VLTI ENVIRONMENT
TECHNICAL FUNCTIONALITY
SCIENCE EXAMPLES
AMBER & MIDI
DATA REDUCTION
FINDING DOCUMENTATION
PREPARING OBSERVATIONS

Documentation of MIDI and AMBER



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

Documents: Call for Proposals (CfP), Instrument User Manuals, Instrument and Operations Webpages.

ESO Call for Proposals – P86

Proposal Deadline: 31 March 2010, 12:00 noon CEST

Call for Proposals

ESO Period 86

Proposal Deadline: 31 March 2010,
12:00 noon Central European Summer Time

Issued 26 February 2010

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.

  -> Presentation by Gerard van Belle.

- Second generation VLTI instruments.

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)	*K*=7.5 (current)
Limiting magnitude AT	*N*=0.74 (current)	*K*=5.5 (current)
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 8-200m	260 - 10 mas	25-1 mas (*J*), 60-2 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)

Baseline configurations

- All available UT 2-telescope baselines for MIDI and 3-telescope triplets for AMBER. Baseline between 47m and 130m.

- ATs are offered in three quadruplets:

  A0-G1-K0-I1, baselines between 47m and 128m

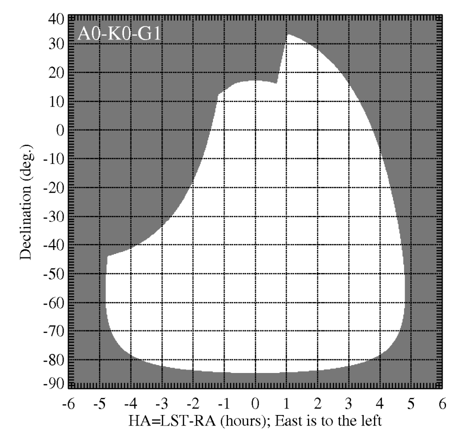
  D0-H0-G1-I1, baselines between 32m and 82m

  E0-G0-H0-I1, baselines between 16m and 68m

  Phase 1: Choice of quadruplet

  Phase 2: Choice of MIDI baseline or AMBER triplet

- Sky constraints due to shadowing and delay line limits



ESO telescope bibliography/ Science Examples

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

As of 26 Feb June 2010:

- 46 publications based on VINCI data
- 67 publications based on MIDI data
- 36 publications based on AMBER data

- 136 publications based on VLTI data
- 71 different first authors (23 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.

Observing programs: 313 AMBER, 272 MIDI, 546 VLTI programs (scheduled)
102 AMBER, 84 MIDI, 156 VLTI PIs from 15 countries

Literature on the instruments

- AMBER:

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

Interferometric data reduction with AMBER/VLTI. Principle, estimators, and illustration, Tatulli et al. 2007, A&A, 464, 29

- 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:

Recent progress at the Very Large Telescope Interferometer, Schöller et al. 2006, SPIE 6268, 19

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

Technical description of MIDI and AMBER

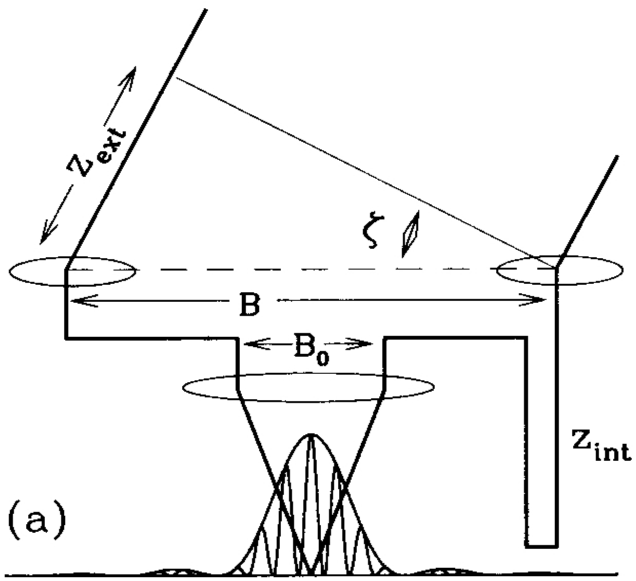
Elements of an interferometric instrument

- Beam combination
- Spatial filtering
- External fringe tracking
- Photometric calibration
- Spectrograph
- Detector

Beam combination

AMBER

Image plane

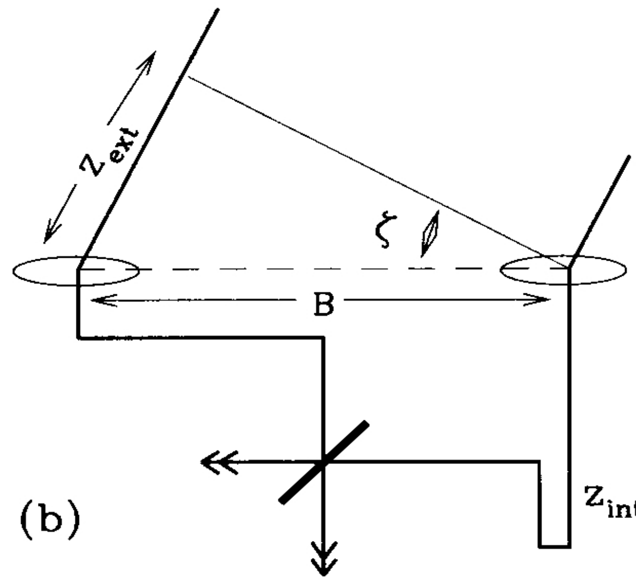


Spatial fringe detection

(geometric delay)

MIDI

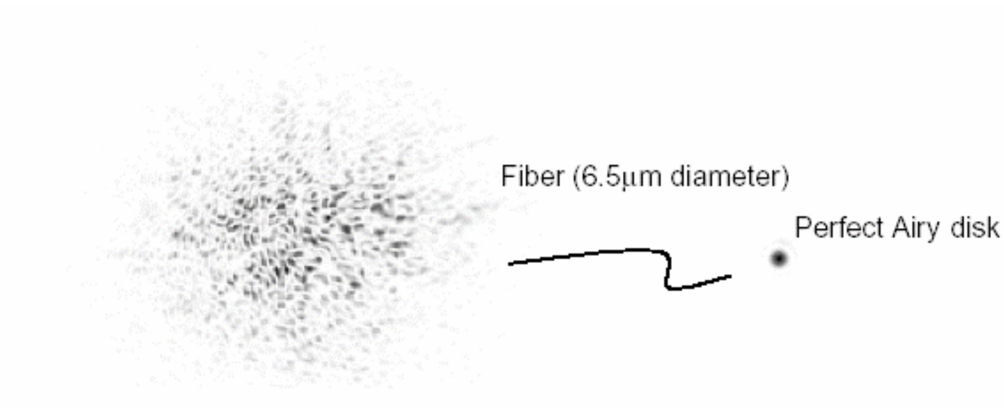
Pupil plane



Temporal fringe detection

(temporal delay modulation)

Spatial filtering



AMBER

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

MIDI

Pinholes, slits.

External fringe tracking

FINITO:
- Three beam fringe tracker operating in the H-band.
- Measures the relative phase difference between the light beams.
- Piston disturbances due to atmospheric turbulence are identified.
- Correction signal is sent to the delay lines over short periods of time (typically 1 msec).

AMBER

Used as a standard for most observations.

Enables the use of longer DITs and the read-out of the full spectral bands in MR & HR modes.

MIDI

Offered only in visitor mode.

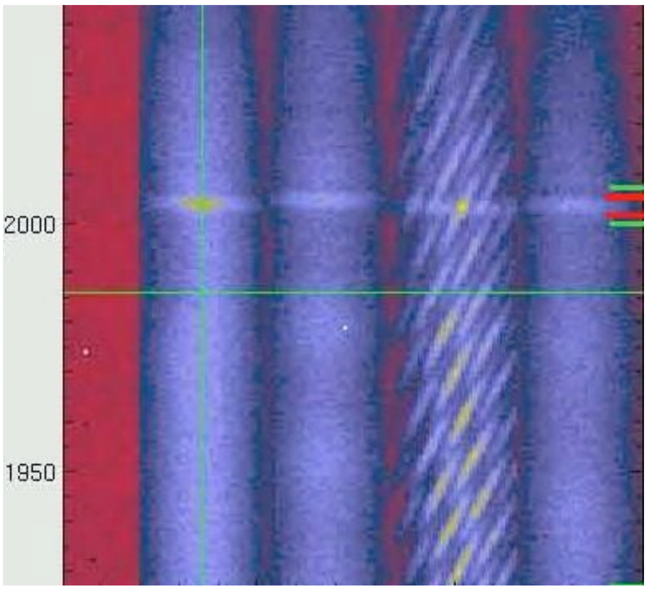
Limiting uncorrelated magnitude unchanged.

Improved correlated magnitude, i.e. lower visibilities can be measured

Requires:
H: -2..5 (ATs), 1..7 (UTs)
Visibilitiy in *H*: >15% (ATs), >10% (UTs)

Photometric calibration

AMBER



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

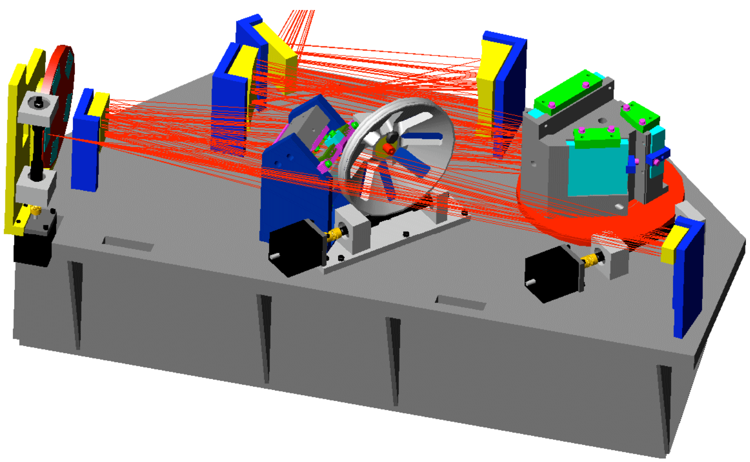
MIDI

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

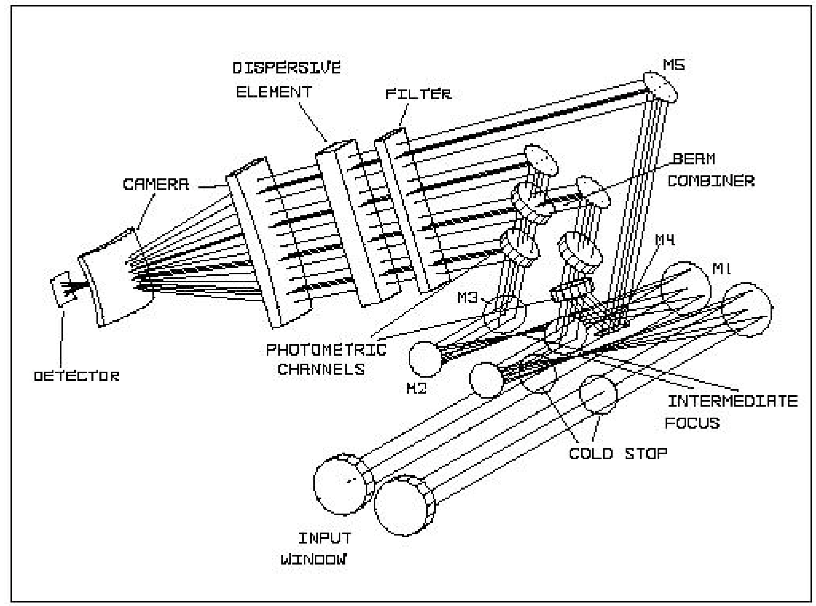
SCI_PHOT mode:
Beamsplitters are used to record the interferometric signal and the photometric Signal simultaneously.

Spectrograph

AMBER



MIDI



Long-slit spectrograph
Prism, LR mode, $\lambda/\Delta\lambda$~30
MR grism, MR mode, $\lambda/\Delta\lambda$~1500
HR grism, HR mode, $\lambda/\Delta\lambda$~12000

Current: LR *HK*, MR *H*, MR *K*, HR *K*

Dispersive element:
NaCl prism $\lambda/\Delta\lambda$~ 30, 1 λ/D=3px=0.26 arcsec
KRS5 grism $\lambda/\Delta\lambda$~230, 1 λ/D=2px along y,
1px along x (disp.)

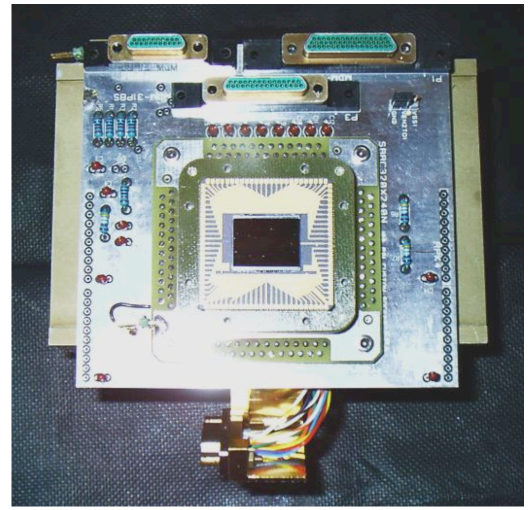
Slit: width 200 μm (0.52/2.29 arcsec for UT/AT)
or field interferometry mode

Detector

AMBER

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

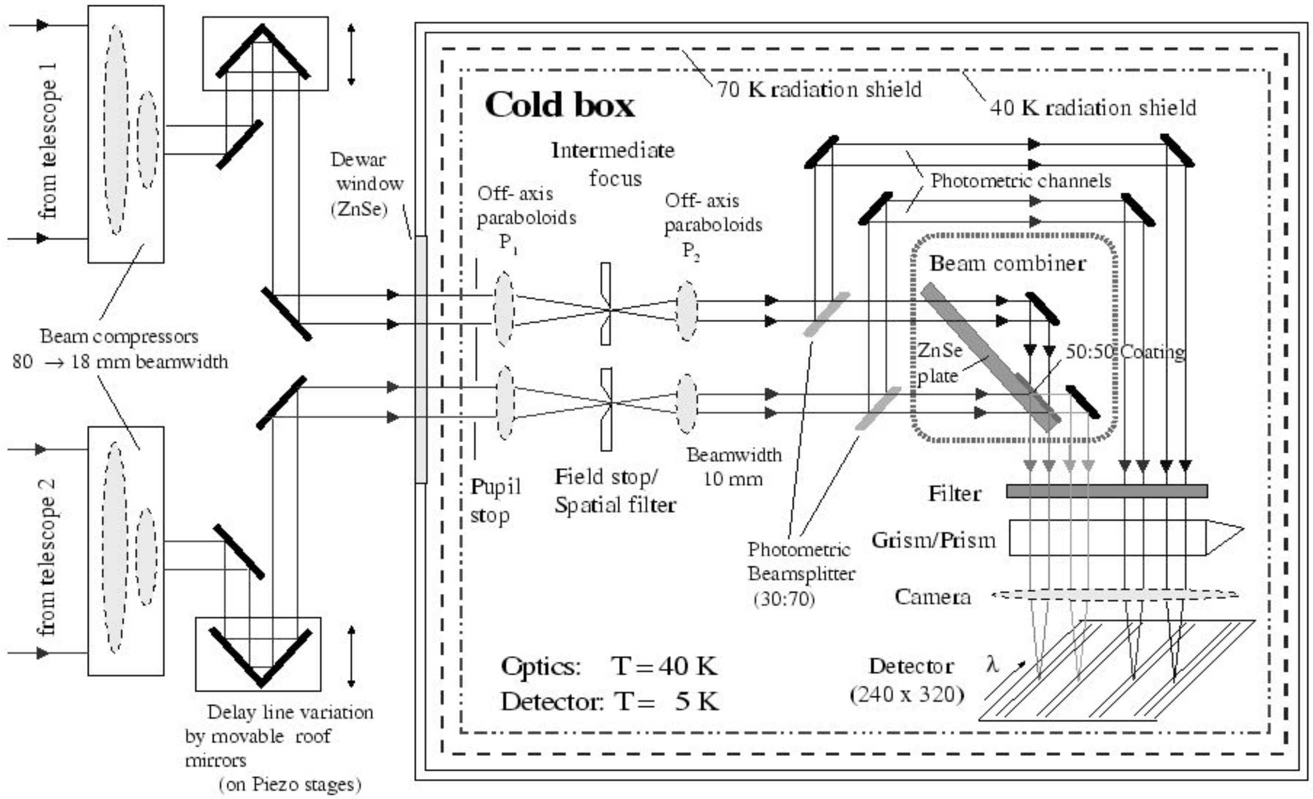
MIDI



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

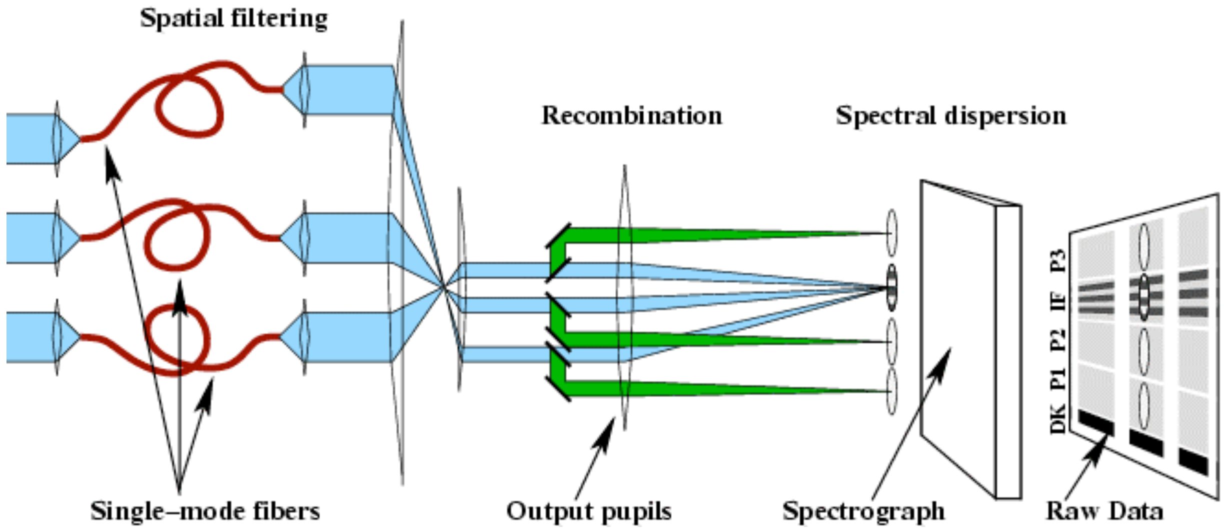
Principle of MIDI - the MID- infrared Interferometer for the VLTI

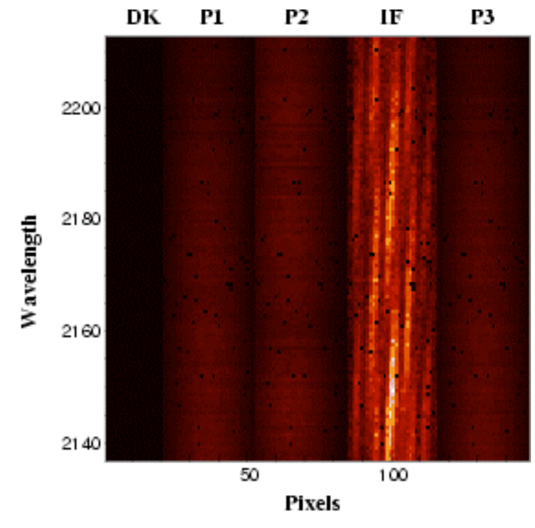


- Light arriving from 2 UTs or 2 ATs, corrected by MACAO or STRAP, IRIS (laboratory tip-tilt), FINITO.
- Time-modulated OPD variations to generate interferograms (warm optics).
- Pupil stops to reduce background and stray-light (cold optics).
- Light focused on field stops (pin-holes for spatial filtering,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

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.

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 1-2 calibration star OBs for each science star OB. The OBs are executed in a row and are considered successfully completed if each of them was executed successfully.

  Different sequences of cal/sci/cal or sci/cal OBs are executed independently.

- The selection of calibration stars is supported by the ESO tool “CalVin” based on different user-defined criteria.

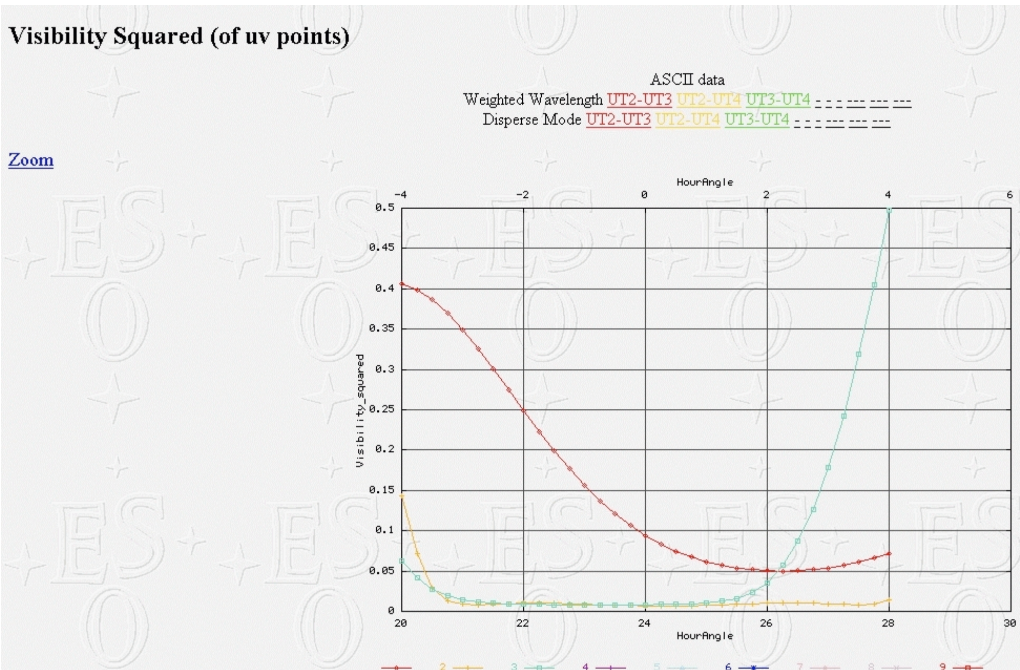
Specific Requirements for Interferometry (II): Combination of different baselines (aperture synthesis)

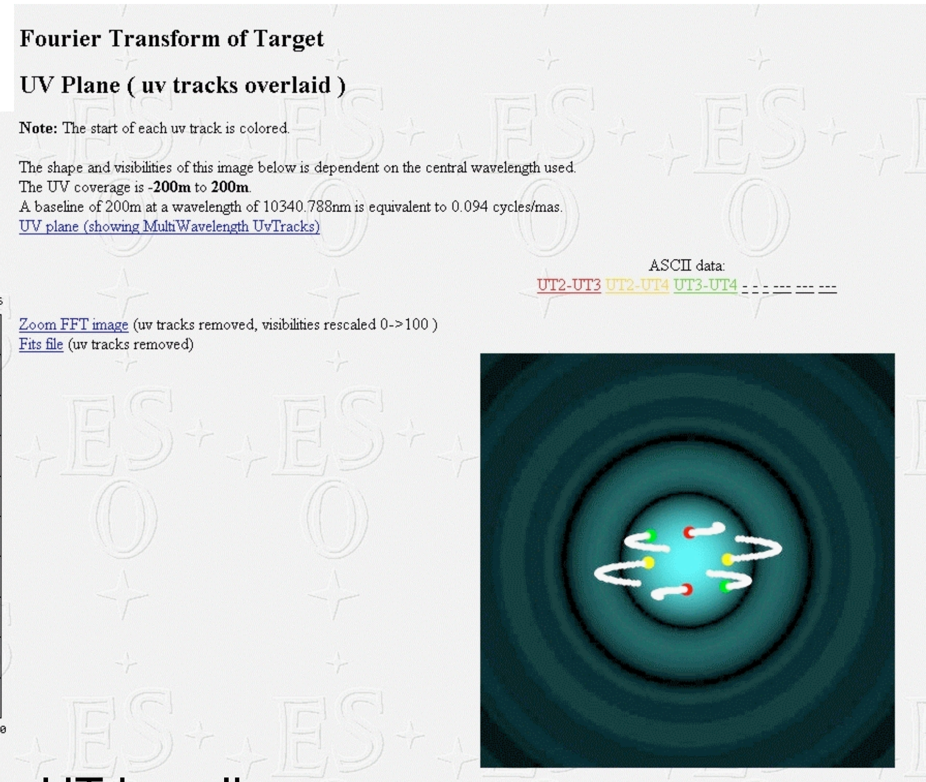
- The scientific goal of an interferometric observing campaign can often only be reached if visibility measurements at different projected baseline lengths and/or angles are combined.

- 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.

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 (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 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 (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 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

Data reduction

- AMBER:

Library amdlib, version 2.2, publicly availabe from
http://www.jmmc.fr/data_processing_amber.htm

- MIDI:

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

INFORMATION NEEDED AT PHASE1 PREPARATION

- Scientific case
- Feasibility of the science case: Brightness in V (off-axis guide star)? Brightness at K band ? Brightness at H band (for FINITO) ? Angular size ?
- Baseline configuration(s)
- Number of visibility points
- Absolute visibility calibration (cal-sci-cal sequence) or relative visibility (cal/sci pairs)
- Spectral resolution
- Required conditions for the correlated magnitudes
- Use of the fringe tracker FINITO ?

INFORMATION NEEDED AT PHASE 2 PREPARATION

- All the information from Phase 1
- Choice of a MIDI baseline, AMBER triplet
- Definition of LST constraints for each visibility point
- Selection of a calibration star that is observable at the same LST

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 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.