AMBER and MIDI from user's point of view

EuroSummer School

Observation and data reduction with the Very Large Telescope Interferometer

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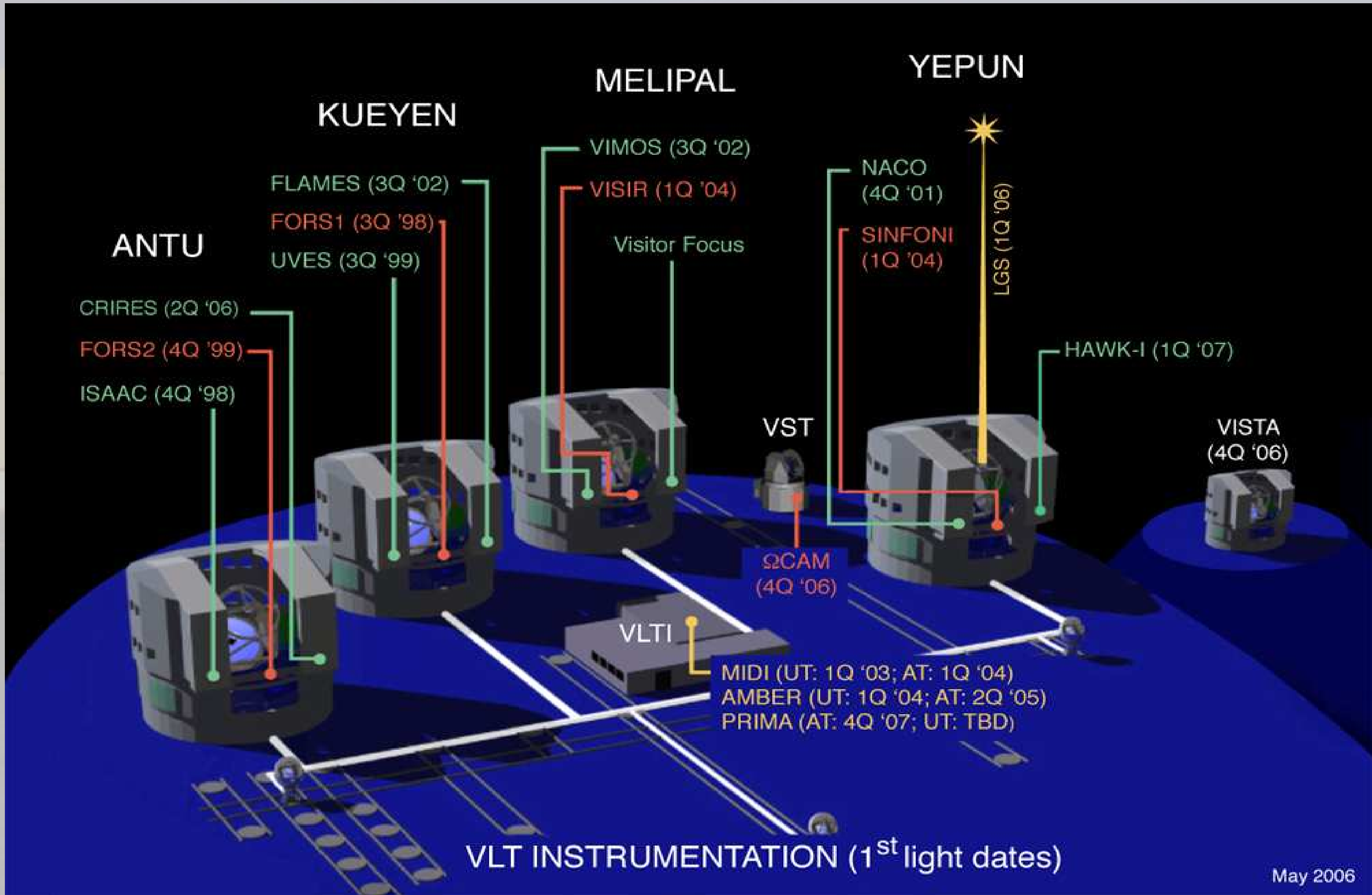
9 June 2006

Outline

- The MIDI instrument.
- The AMBER instrument.

- Observing with ESO telescopes.
- ESO preparation tools VisCalc and CalVin.
- VLTI specific parts of Phase 1 and 2 proposal preparation.
- Execution of observations.
- Pipelines, quality control, data delivery. ESO archive.

VLT/VLTI 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.

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

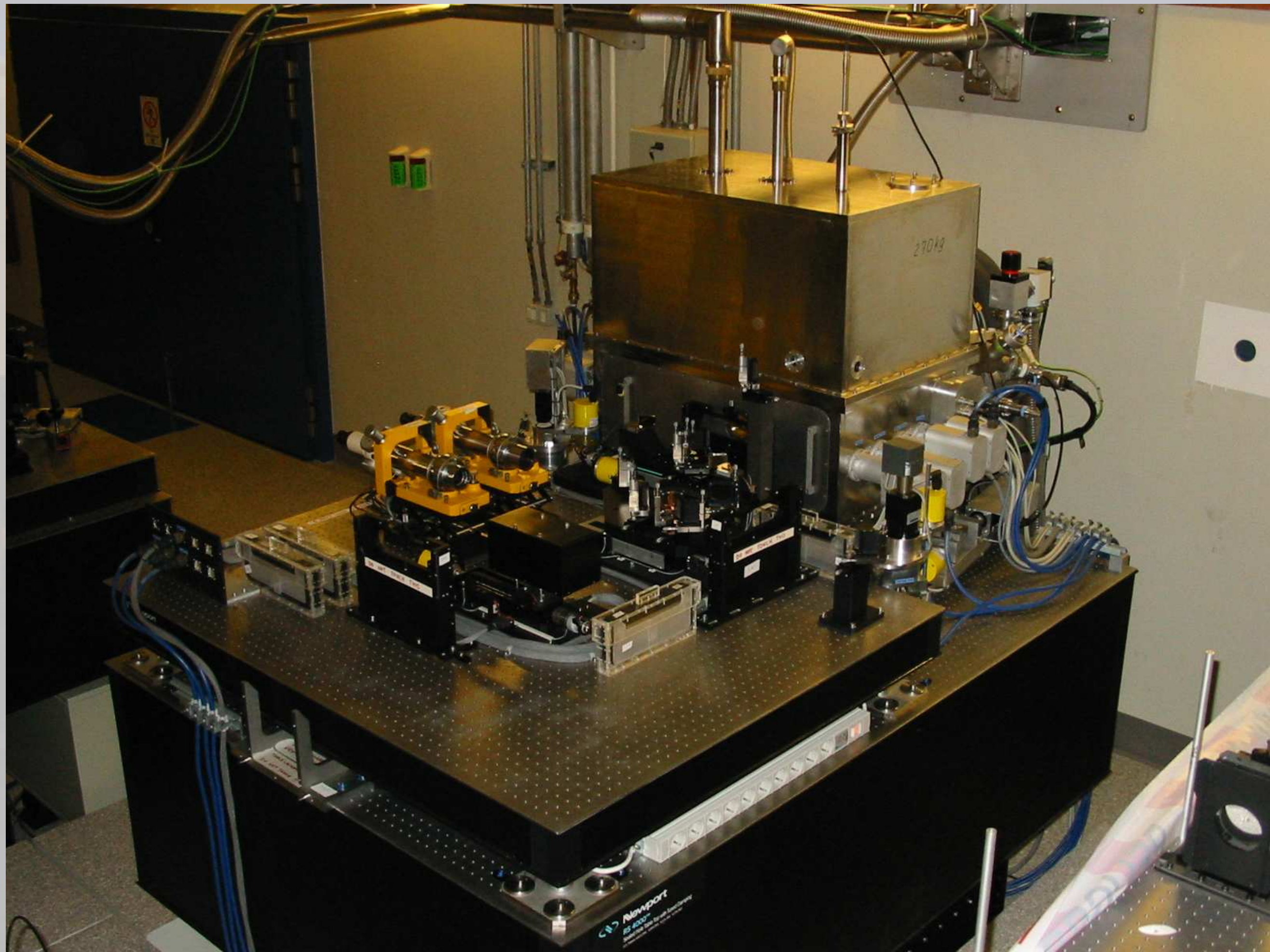
Result: 3 visibility spectra and 1 closure phase spectrum per obs. (+photometry).

PRIMA: Phase Referenced Imaging and Micro-arcsecond Astrometry.

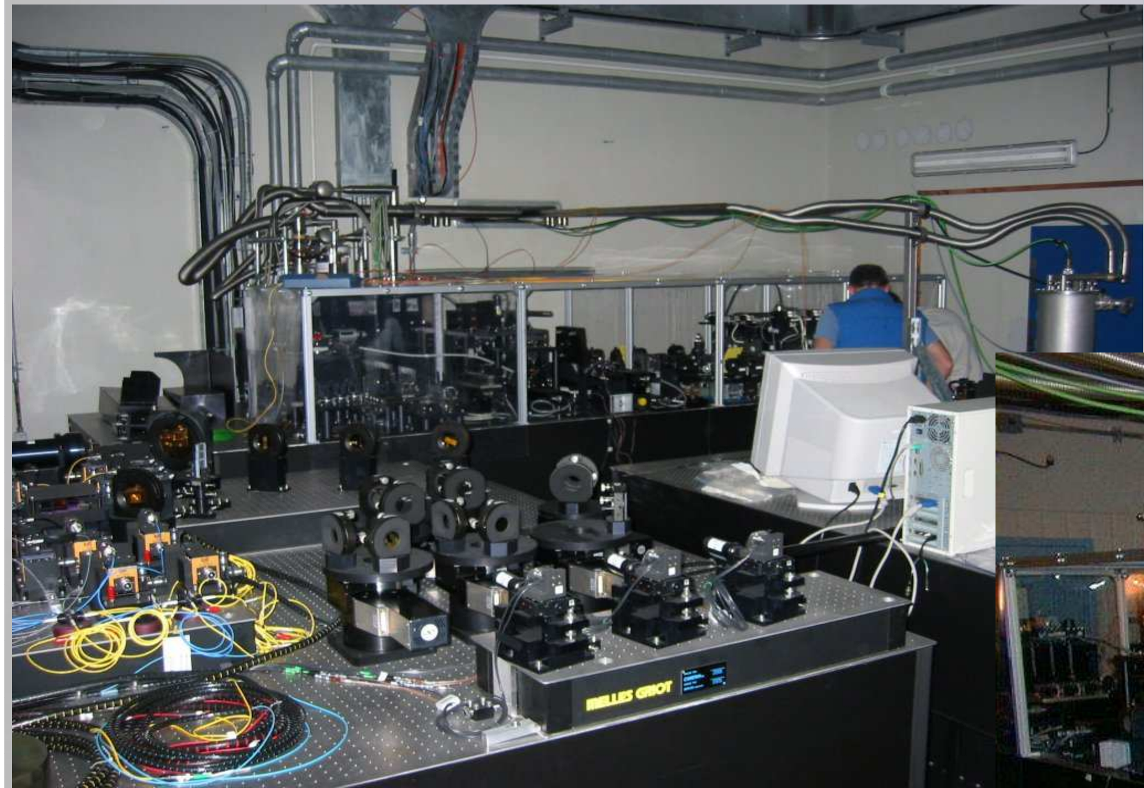
VLTI instruments and their operation are designed along the same lines of VLT instruments, in particular for what concerns the integration into the end-to-end VLT operations scheme .

Both instruments represent first-timers in their areas. ESO approach to provide interferometry at the same level as any other astronomical observation also represents a first-timer.

MIDI in the VLTI Lab



AMBER in the VLTI Lab

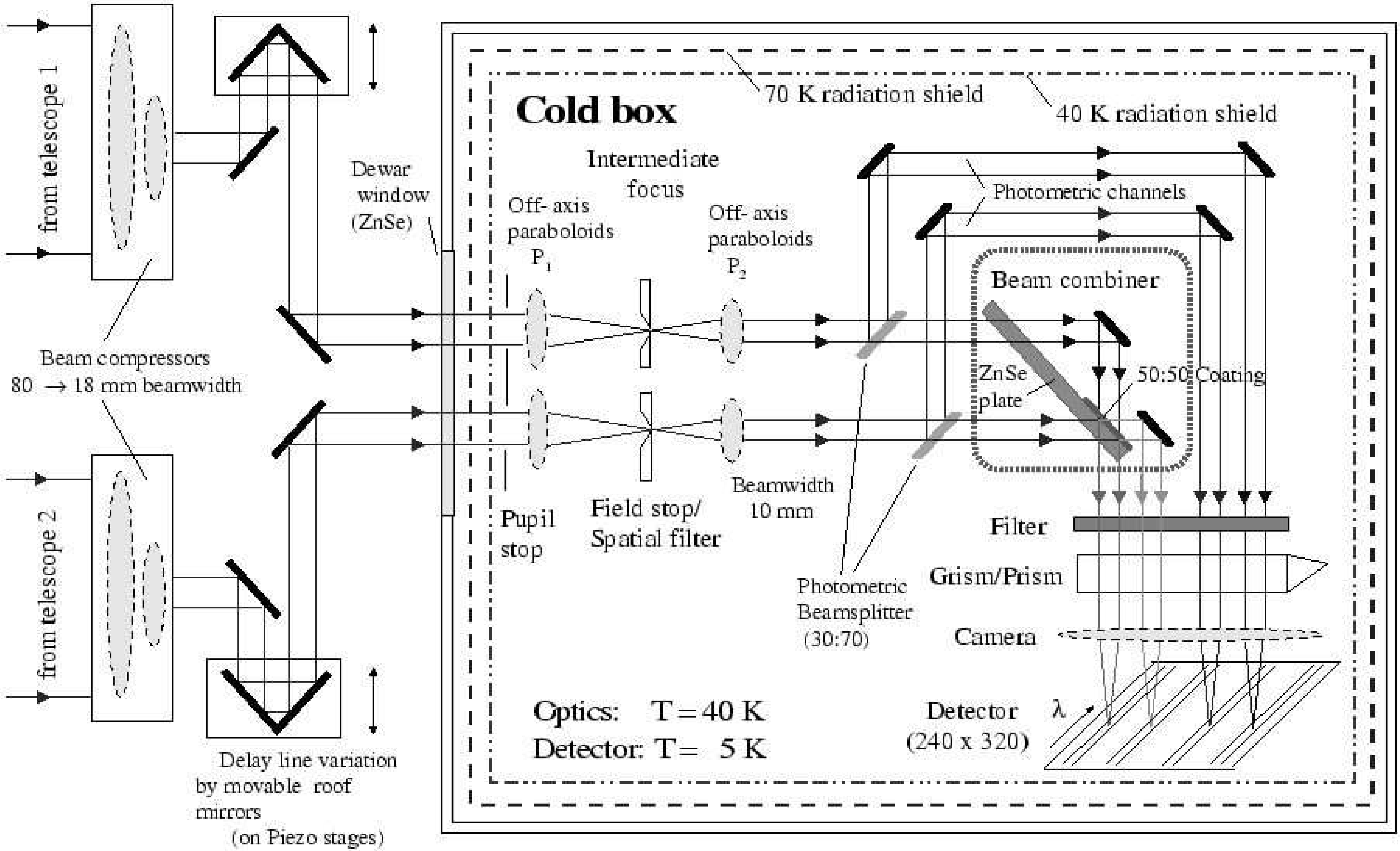


Overview of MIDI and AMBER

	MIDI	AMBER
Consortium	D/F/NL	F/D/I
PI	Ch. Leinert (Heidelberg)	R. Petrov (Nice)
UT First Fringes	Dec. 2002	Mar. 2004
Beams	2	3
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 (FT)	K=7 (current) K=11 (FT), K=20 (PRIMA)
Limiting magnitude AT	N=0.25 (current), N=5-6 (FT)	K~8 (FT)
Visibility accuracy	<20% (1-5%)	1% (diff.), 3% (abs.)
Airy disk FOV	0.26'' (UT), 1.14'' (AT)	60 mas (UT), 250 mas (AT)
Diffraction limit, 200m	10 mas	1 mas (*J*), 2 mas (*K*)

MIDI: technical principle

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



The principle of MIDI

- Light arriving as collimated beams (18mm width) from either 2 UTs or 2 ATs, corrected by MACAO (UTs, V<=17) or STRAP (V<=13) and IRIS (laboratory tip-tilt). Later: also phase-stabilized by FINITO/PRIMA.
- 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 simultaneous photometry.
- 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).

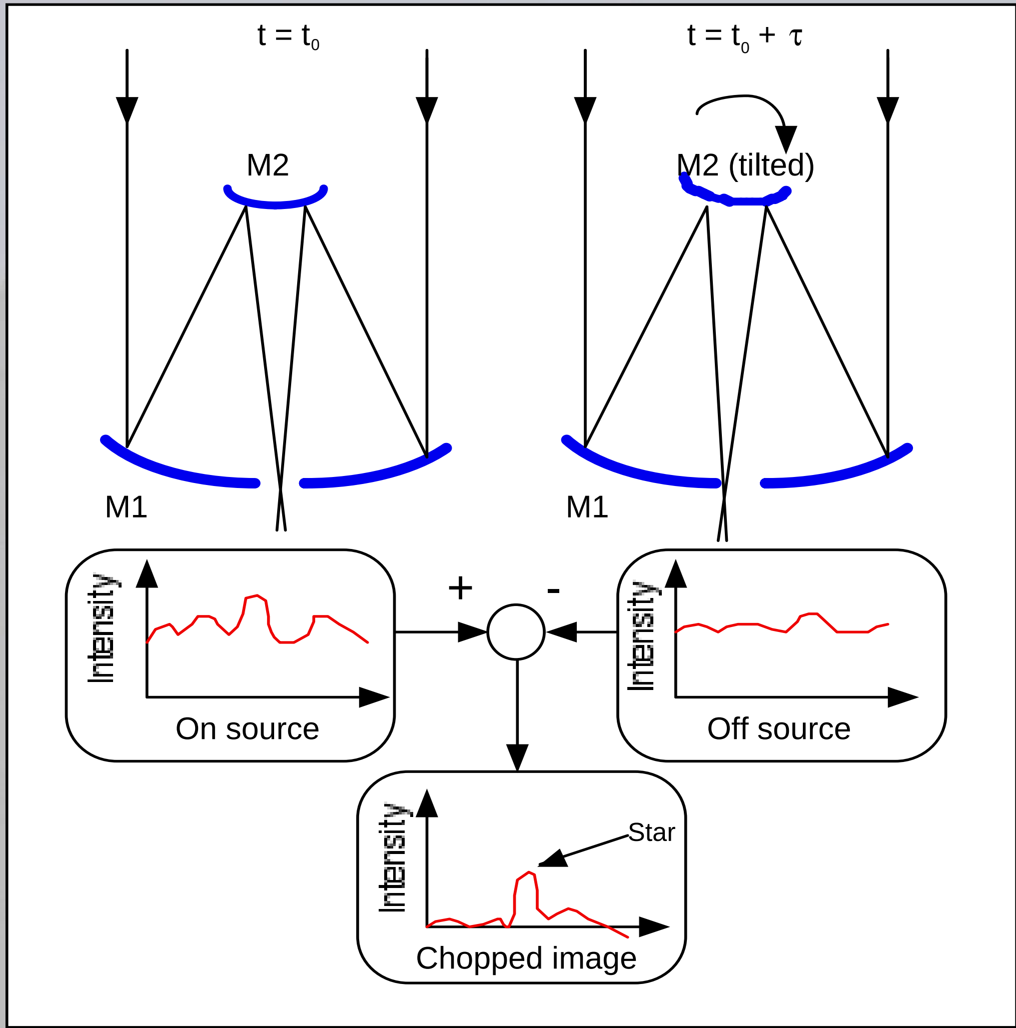
CHOPPING for MIDI

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

Thermal emission of optics proportional to εT^4

Mirrors: $\varepsilon \approx 0.05$

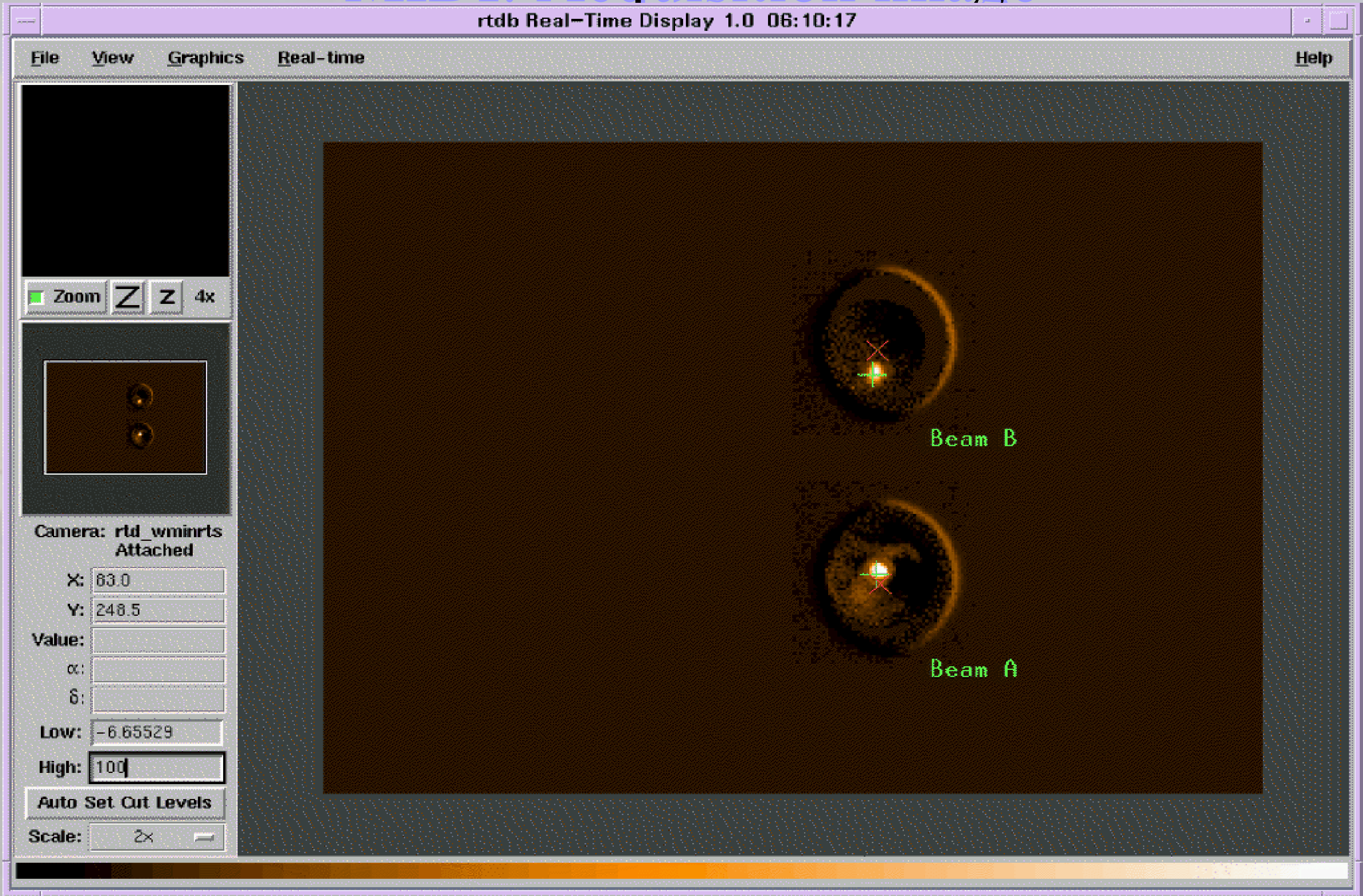
$\Rightarrow$Requirement for chopping for photometric exposures (typically 2 Hz)



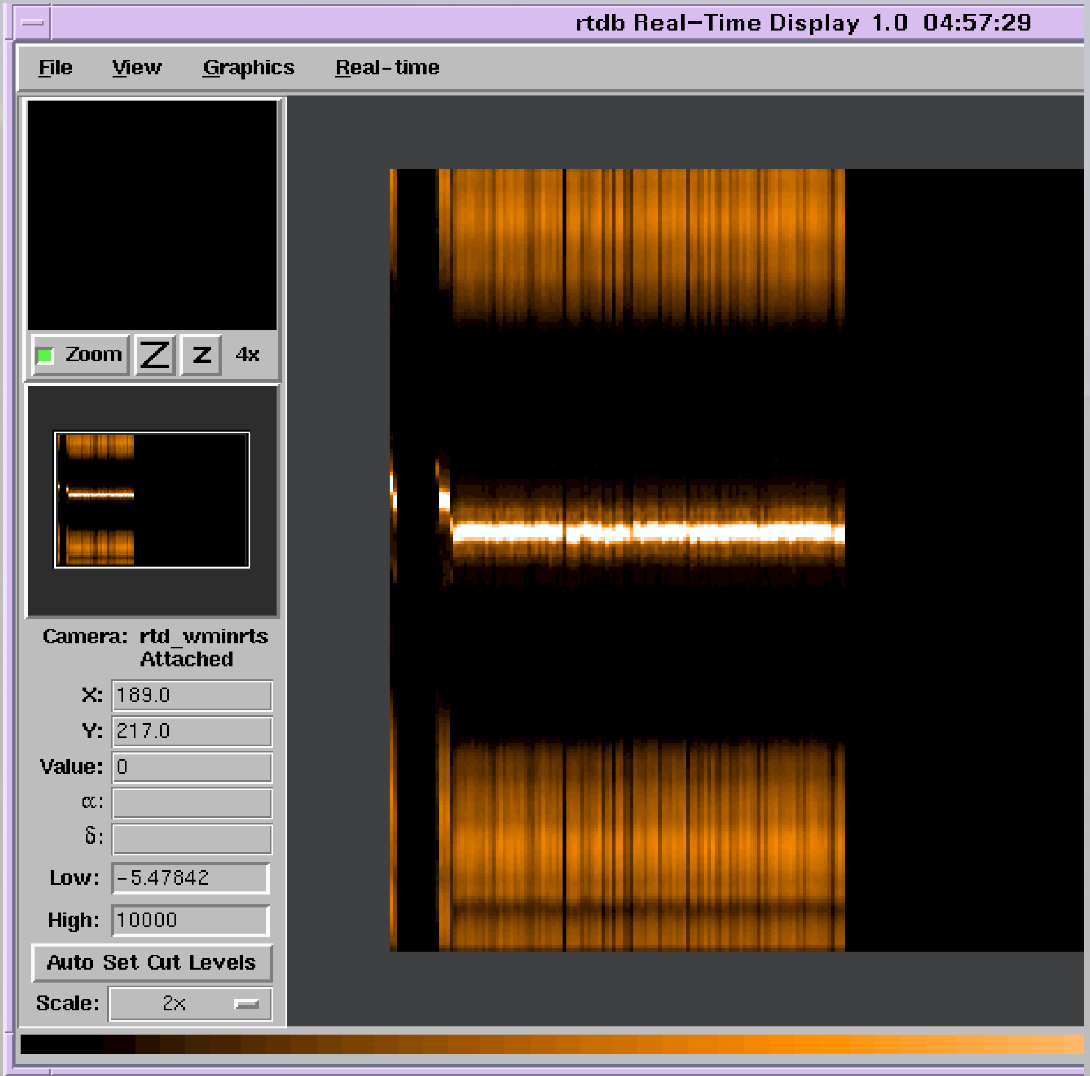
MIDI: Observational procedure

1. Acquisition: Telescopes and delay lines pointing the target. MIDI is setup to provide images of the beams (FOV 2 arcsec at UTs). Position of the beams is adjusted to provide beam overlap. Filter for the acquisition images can be chosen.
2. Fringe exposure: Beams are dispersed along the horizontal axis of the detector with either a NaCl prism (R=30) or a KRS5 grism (R=230). Fringes between the two interferometric outputs are phase-shifted by 180 deg., and subtraction removes background noise. The zero-OPD point is computed in real time for each scan and converted into an offset to the tracking delay line. HIGH_SENS (no simultaneous photometric output) or SCI_PHOT (simultaneous photometric outputs) setups can be used. Chopping is not used for HIGH_SENS mode.
3. Photometry: Photometric exposure after every fringe exposure in HIGH_SENS mode, and once a night in SCI_PHOT mode (for kappa matrix). Always using chopping.

MIDI: Acquisition image



MIDI: Fringe exposure



AMBER: technical principle

Scheme of the AMBER principle

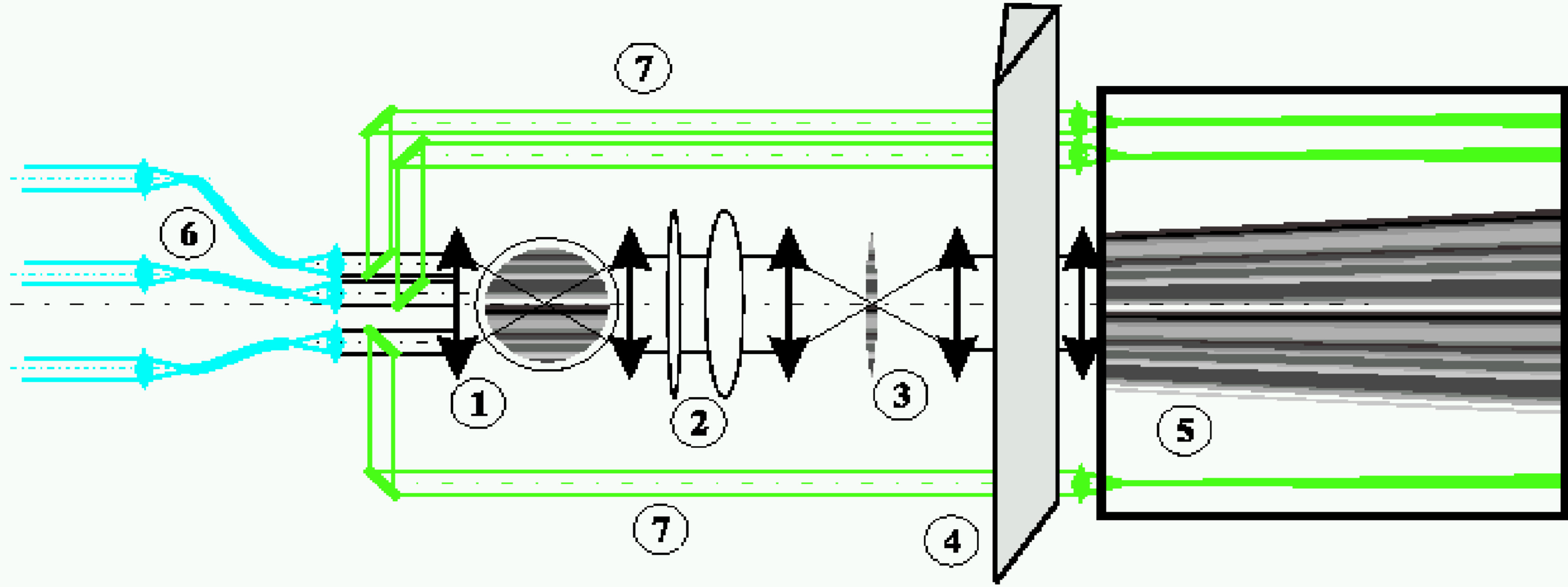


Figure 1: Basic concept of AMBER: (1) multi axial beam combiner. (2) cylindrical optics. (3) anamorphosed focal image with fringes. (4) "long slit spectrograph". (5) dispersed fringes on 2D detector. (6) spatial filter with single mode optical fibers. (7) photometric beams.

The principle of AMBER

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 (spatial filter module). Photometric channels are separated.

The three incoming collimated and parallel beams form a non-redundant set up, and are focused in a common Airy pattern that contains the fringes (beam combination in image plane).

Each spectral channel is concentrated in a single column of pixels (cylindrical optics) to reduce noise.

Also, alignment unit, neutral density filters, polarisors,…

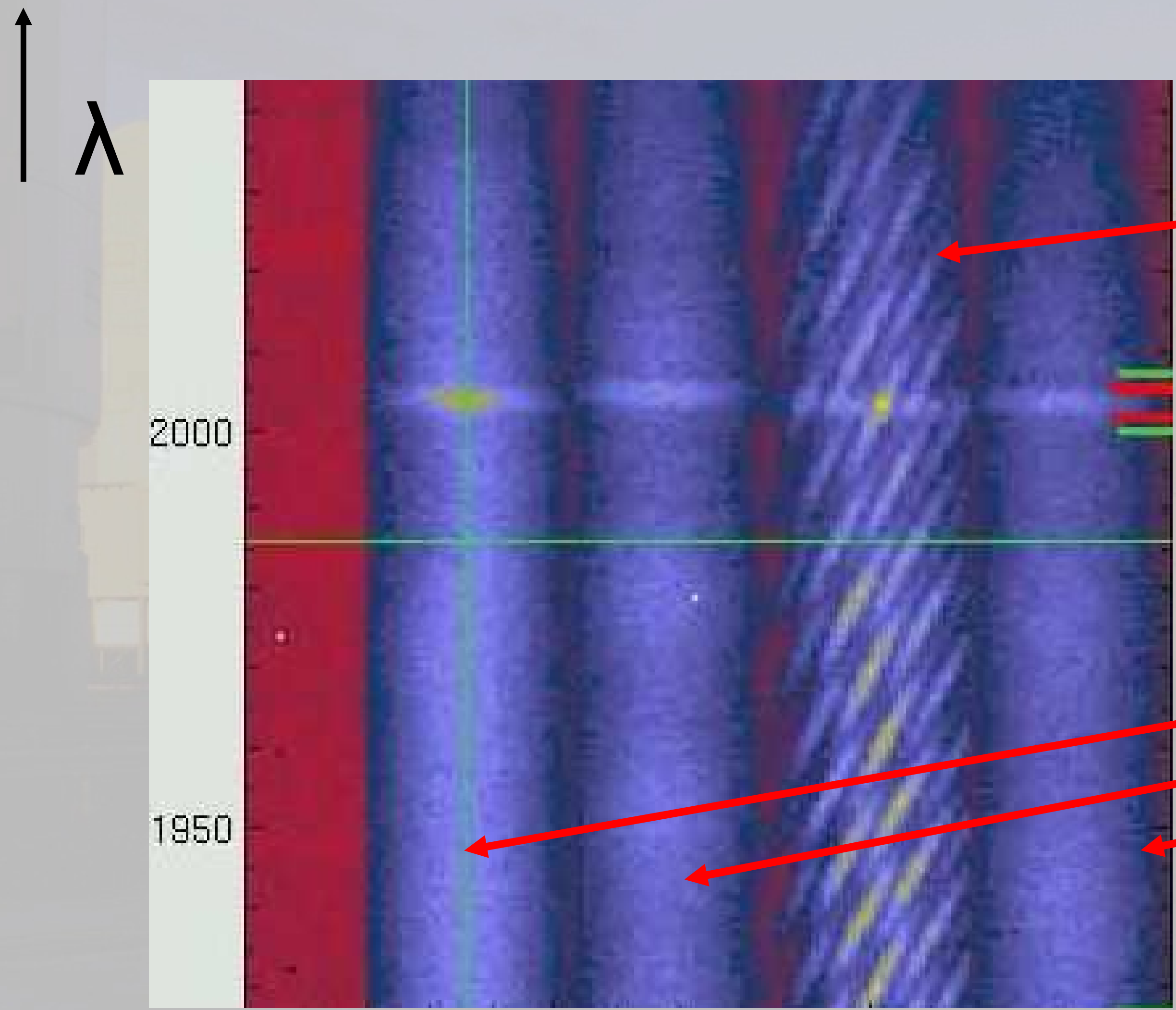
Spectrograph: Dispersion by a standard long-slit spectrograph (3 different spectral resolutions of R = 30, 1500, 12000). Includes an image plane cold stop and a cold pupil masks.

Detector: One quadrant of a 1024x1024 pixel Hawaii detector. Quantum efficiency 0.8, readout noise 11.37 e^-.

AMBER: observational procedure

1. Instrument setup: desired wavelength range, spectral resolution, and detector integration time. Internal calibration of the chosen instrument configuration.
2. VLTI setup: Pointing of telescopes and delay lines, use of MACAO (UTs) or STRAP (ATs), IRIS.
3. Injection adjustment: Telescope positions are adjusted so that the beams are centered on the injection fibers.
4. Fringe search by offsetting the tracking delay line.
5. Fringe exposure.

AMBER raw data



Interferometric

beam:

3-telescope

interferogram

3 photometric
beams of 3
telescopes

(lab data)

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.

	MIDI in P78	AMBER in P78
UT baselines	All 2 telescope baselines.	All 3 telescope configurations.
MACAO at UTs	$1<V<17$, distance<57.5 arcsec. Mandatory in service mode.	$1<V<17$, distance<57.5 arcsec. Mandatory.
AT baselines	16m, 32m, 64m.	Not yet.
STRAP at ATs	V<13, distance < 60 arcsec. Mandatory.	/
IRIS lab. guiding	Yes. *H*-band.	Yes. *H*-band.
Configurations	Prism (R=30) or Grism (R=230) HIGH_SENS or SCI_PHOT	LR-K, LR-HK (*R*=35) MR-K 2.1 or 2.3 µm (*R*=1500) HR-K (*R*=12000) DIT: 25 msec, 50 msec.
Limiting magnitude	*N*=4 or 1 Jy at 12 µm (UTs). *N*=0.25 or 50 Jy at 12 µm (ATs).	*K*=7 (LR); *K*=4 (MR); *K*=1.5 (HR)
Time	60 min. per calibrated visibility.	90 min. per calibrated vis.
Precision	< 20%.	V>0.1 required. 3% accuracy.

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. Everything is accessible from http://www.eso.org/observing.

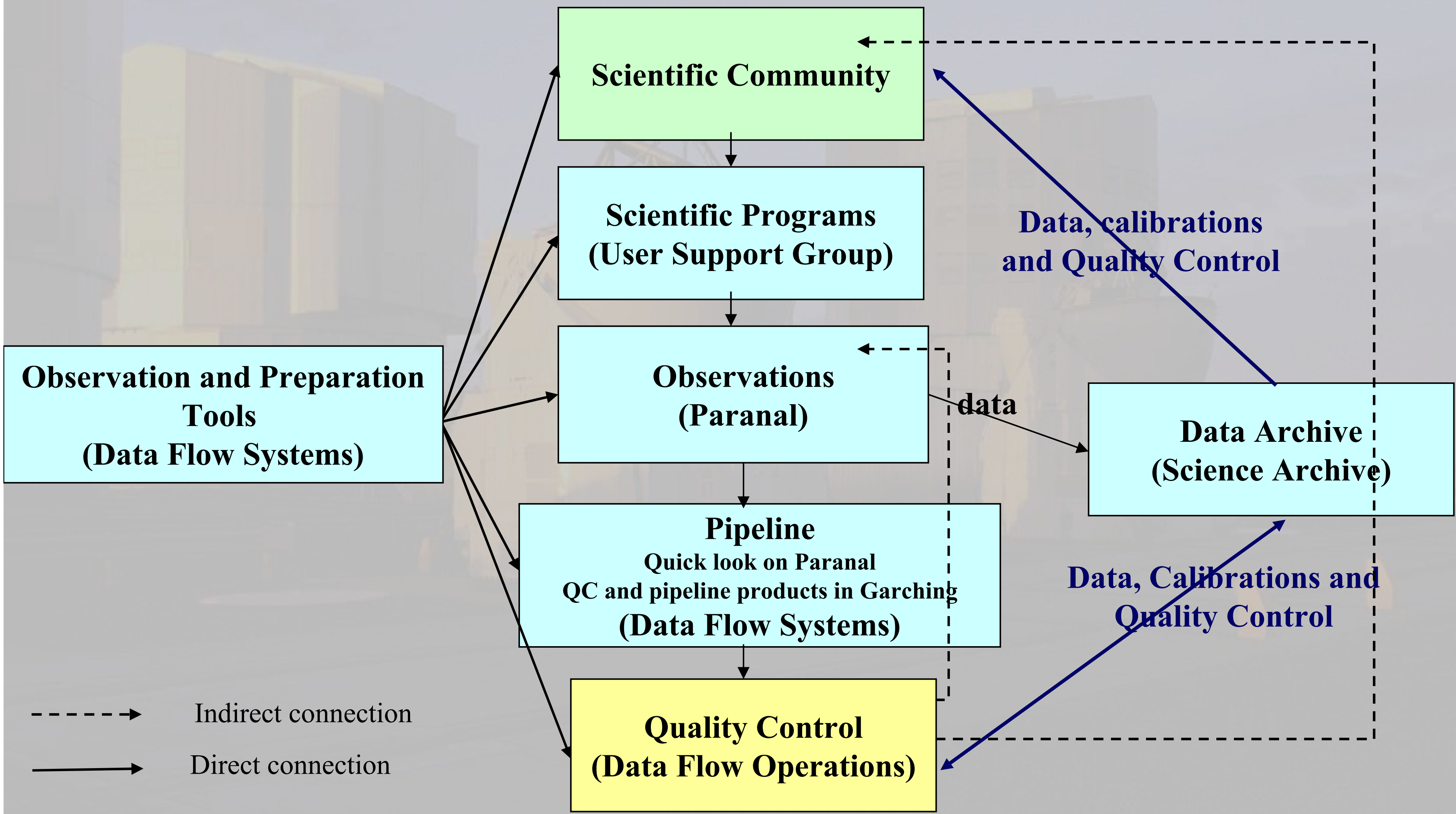
Preparation tools: VisCalc (Visibility Calculator) and CalVin (Calibrator Sel.)

Overview: “Observing with the VLT Interferometer”, The Messenger 119, 14 (2005)

Observing with VLT/VLTI instruments

1 March/ 1 September	Issue of the Call for Proposals (CfP).
	Phase 1 proposal preparation. Point of contact: User Support Dep.
1 April/ 1 October	Deadline for proposal submission.
	OPC review.
	Technical feasibility and Scheduling.
End of June/ End of December	Announcement of observing time.
	Phase 2 proposal preparation. Service: User Support Department. Visitor: Science Operations Paranal.
Early August/ Early February.	Phase 2 deadline for service mode.
Oct-Mar/Apr-Sep	Observations. Resolving Problems. Possibly adjustment of configurations. Quality control.
Once a run is completed or terminated.	Data delivery.

VLT/VLTI data flow (service mode)



Past and current observing periods with the VLTI

	# of progr.	# in service	# in visitor	Hours service	Nights visitor
P73 MIDI	21	17	4	77 h	3.5 n
P74 MIDI	19	13	6	86 h	2.7 n
P75 MIDI	27	21	6	152 h	7.2 n
P76 MIDI	25	21	5	77 h (UT) + 231 h (AT)	6.5 n (UT)
P77 MIDI	29	19	10	85 h (UT) + 324 h (AT)	3.7 n (UT)
P76 AMBER	21	19	2	71 h	4.0 n
P77 AMBER	15	12	3	51 h	4.4 n

Total allocated time in P77 (UT): ~ 20 nights (x 2 or 3 telescopes).

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 are executed independently.

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.

The calibrator also has to be brighter than the limit of each offered mode !

Specific Requirements for Interferometry (II): Observation Sequences

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 baseline can be specified, as part of the instrument-specific constraint set settings.

The pairs of science/calibrator OBs are effectively 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.

Specific Requirements for Interferometry (III): Scheduling

The choice of baseline and LST range are additional VLTI-specific constraints.

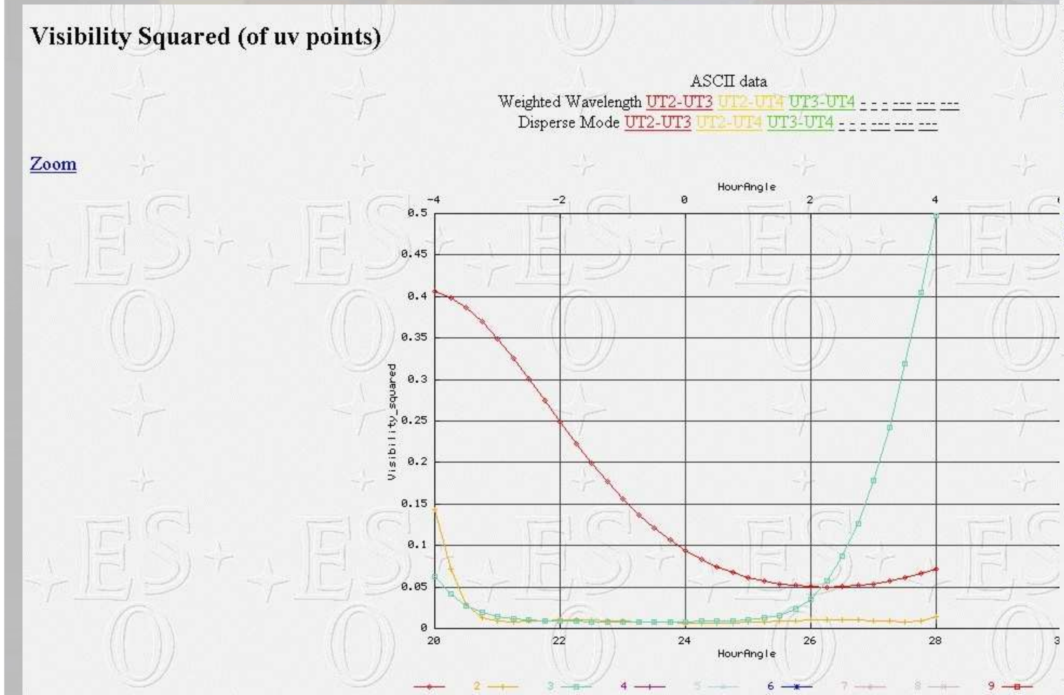
These additions complicate the scheduling.

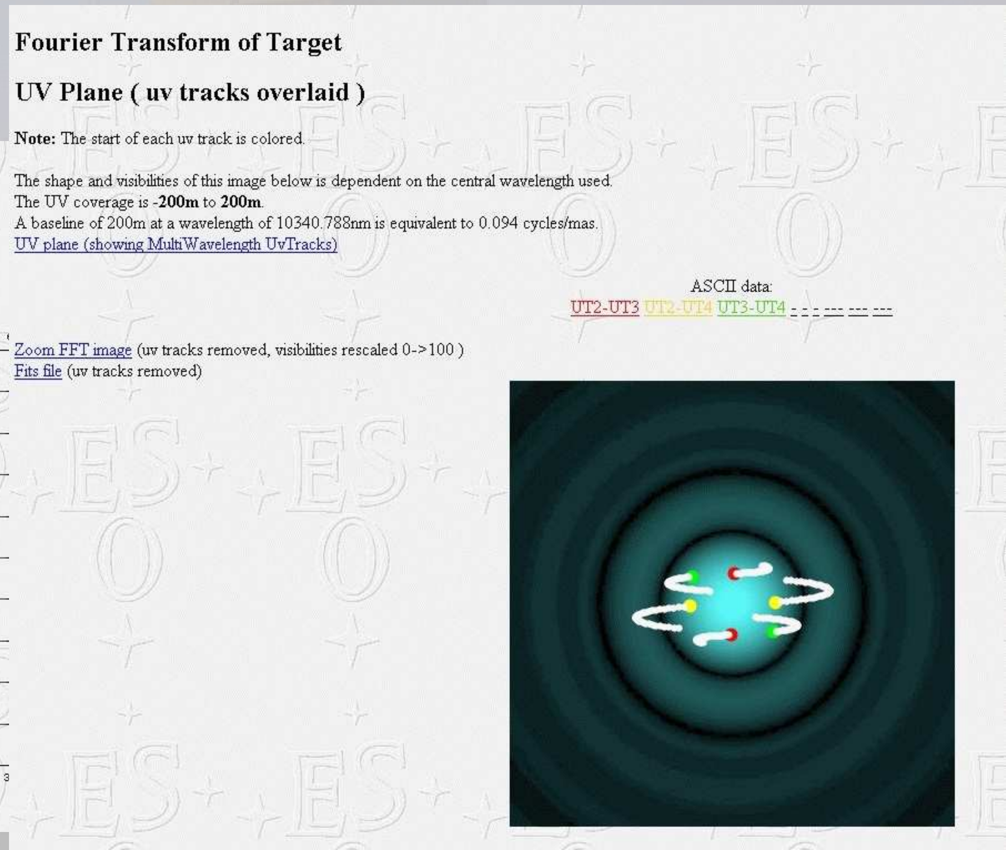
The LST constraints give additional constraints on the time of observation during the night, but also in the course of the year.

It is very advisable not to require too stringent constraints on atmospheric conditions and LST ranges.

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 (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 (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 (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

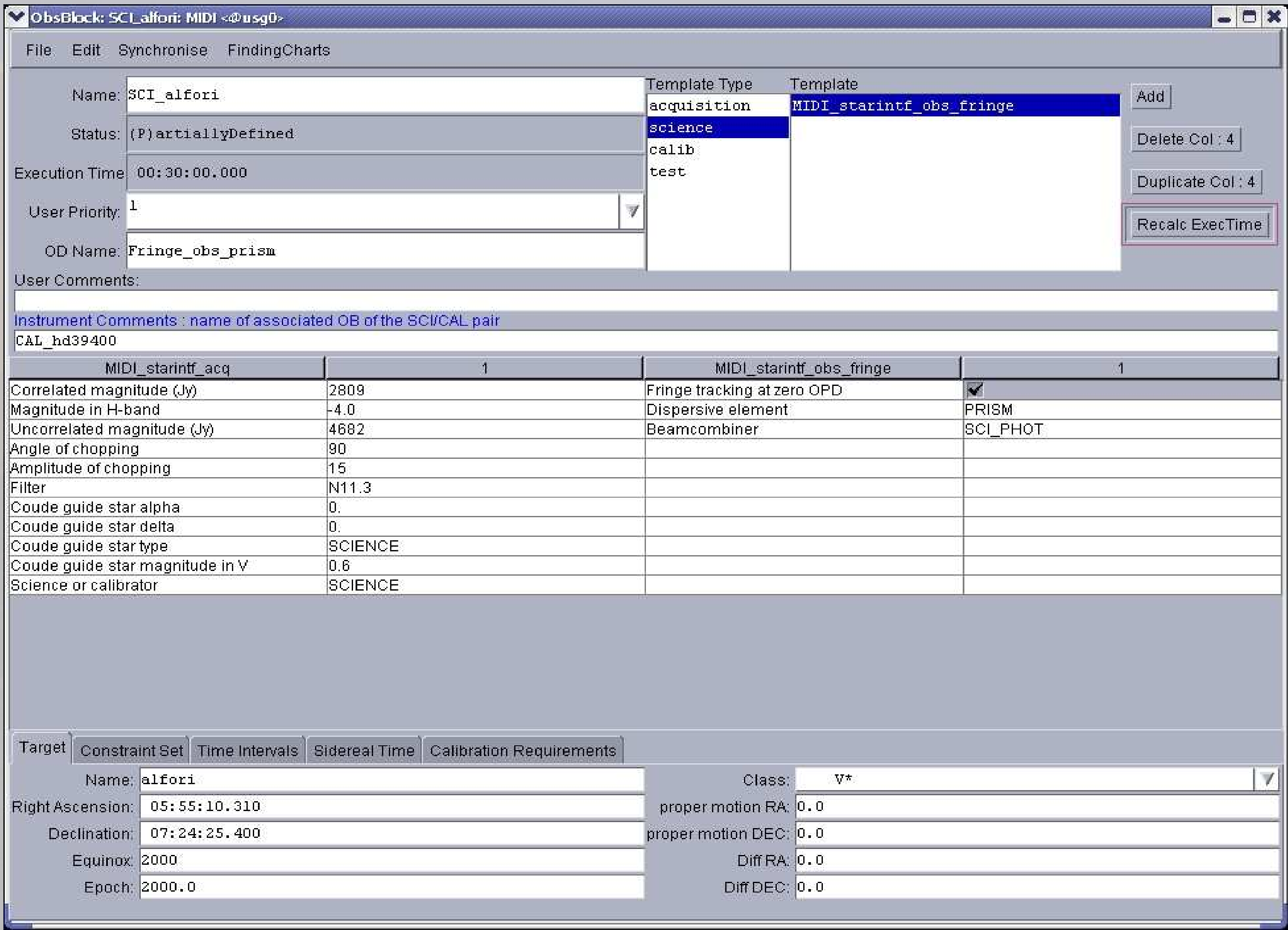
Proposal preparation (Phase 1)

Information needed at time of Phase 1 proposal preparation:

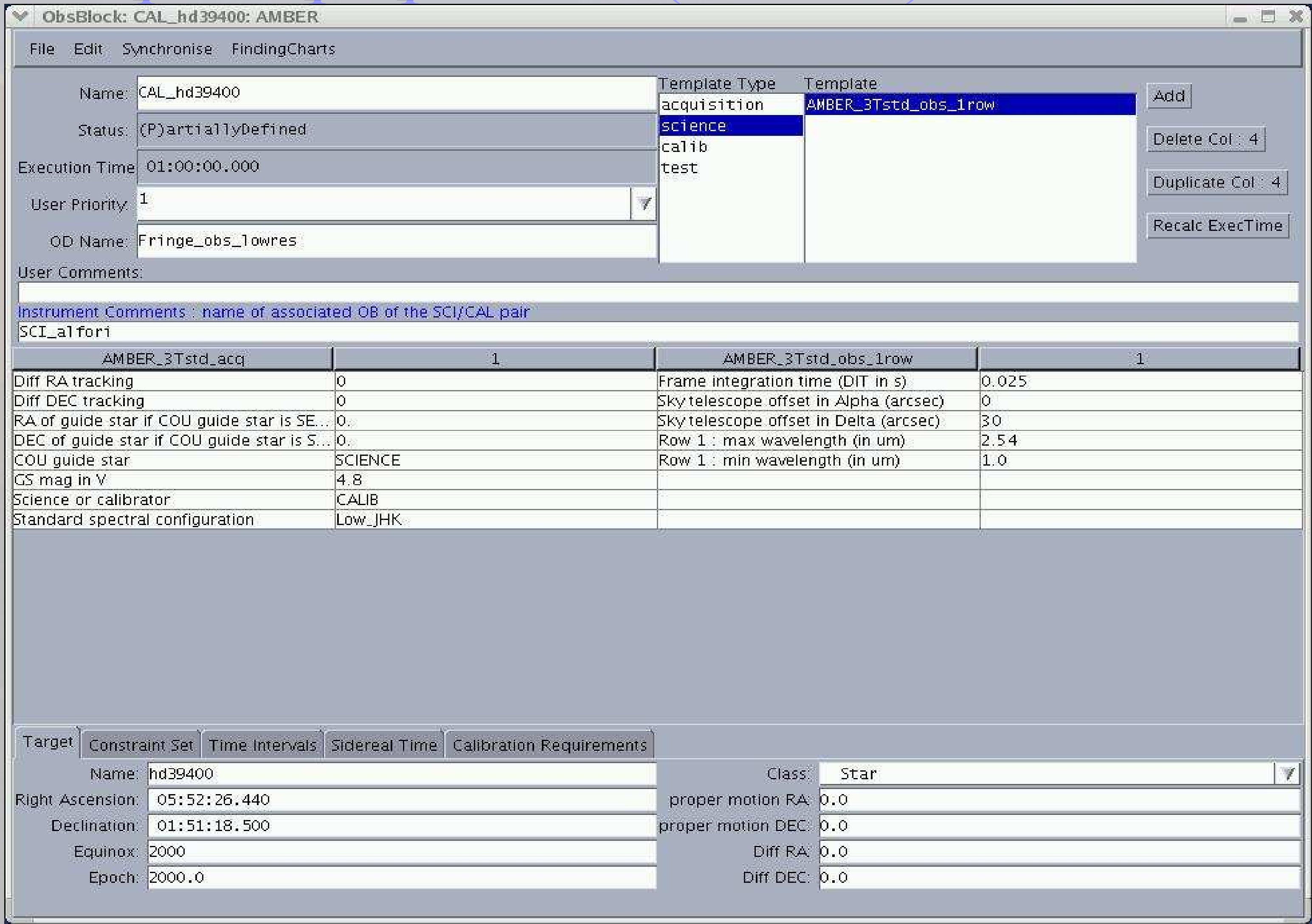
- Definition of runs, where each run corresponds to 1 instrument (MIDI or AMBER) and 1 baseline configuration. Time per run. Preferred month. Seeing (AMBER only), Sky Transparency for each run.
- Proposed target list, with time on target, V magnitude, coordinates, etc.
- Instrument configuration (spectral resolution, high_sens or sci_phot mode for MIDI)
- Interferometric table with V mag., mag. at wavelength of observation, size, baseline, expected visibility and correlated flux, i.e.flux times visibility (from VisCalc).
- Check the ESO archive !

LST ranges and calibration stars are defined at Phase 2, i.e. after acceptance of the program).

Proposal preparation (Phase 2) - MIDI



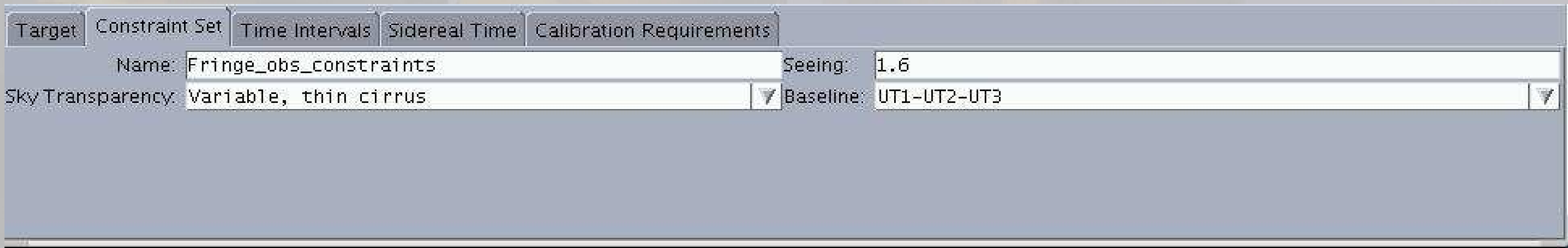
Proposal preparation (Phase 2) - AMBER



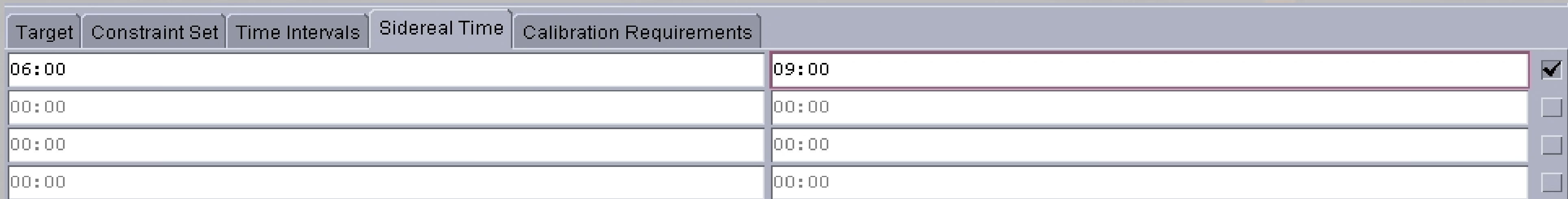
Proposal preparation (Phase 2) – Constraint set

MIDI constraint set:

AMBER constraint set:



LST constraints:



Proposal preparation (Phase 2)

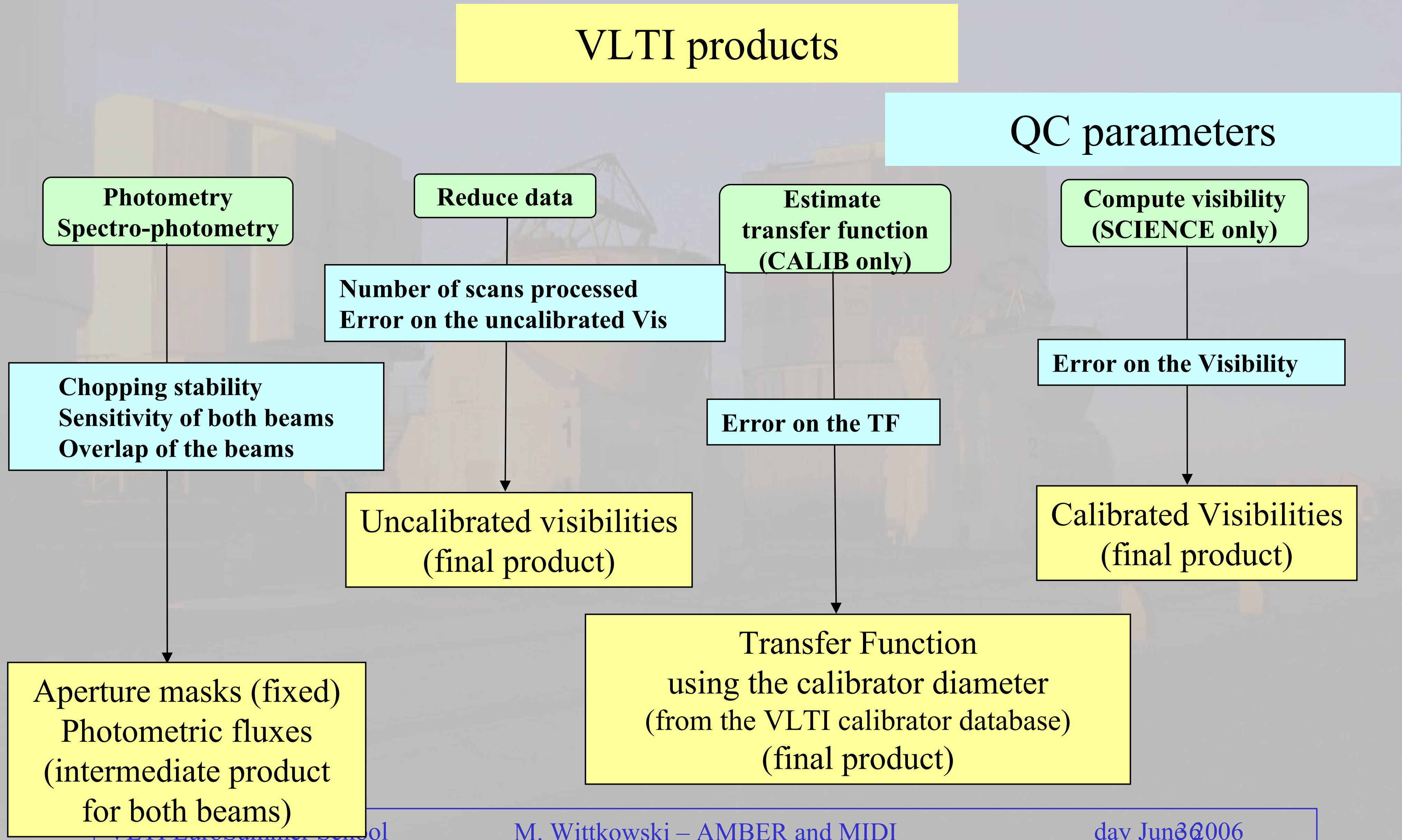
From www.eso.org/observing/p2pp:

- General service mode instructions.
- Description of policies for waiver request, target changes, etc.
- Instrument-specific instructions.
- Instrument-specific tutorials.

From www.eso.org/instruments:

- Instrument user manuals and template manuals.
- Latest updates and information on the instruments.

Pipeline recipes



Quality Control and Data delivery

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.