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Very Large Telescope
Paranal Science Operations
AMBER User Manual

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Change Record

Issue/Rev.	Date	Section/Parag. affected	Remarks
83.0	2008-09-03	Various sections	FINITO use
		1	Limiting Magnitudes
83.1	2008-09-12	1	Limiting Magnitudes
84.0	2009-02-07	most of the doc	removed all VLTI specific parts
		2.5	performance table
85.0	2009-08-26	8	a separate section for Calibration plan
			'cold' darks
86.0	2010-02-27	7.2	1 simple OB is now 25 minutes in LR
		2.5	updated performances in HR-K
		6.1	CAL-SCI-CAL sequence is default
87.0	2010-08-29	8	FINITO tracking info. now recorded
89.0	2011-08-29	7.2	OB duration modified (LR:20min,MR/HR:25min)
		8	Amber self-coherencing described
			Minor improvements to the document
90.0	2012-02-24	1	Simple update - No new features

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Contents

1 INTRODUCTION

AMBER (Astronomical Multi-BEam combineR) interferometrically combines two or three telescopes of the VLTI in the near-IR. It measures simultaneously different interferometric quantities: the fringes visibility, differential (in the sense of wavelength) visibility, differential phase, closure phase and differential closure phase. These quantities allow to obtain spatial information at a very small angular resolution, the best available from any other ESO instruments. AMBER can reach angular resolution of the order of 1 milli-arcsecond (1mas=0.001"), with spectral resolution of R$\sim$35 in H and K band (simultaneously), 1500 in H or K, or 12000 in K band (as of period 90).

1.1 Scope of this manual

This document summarizes the features and possibilities of AMBER, installed at the VLTI, as it will be offered to astronomers for the six-month ESO observation period number 90 (P90), running from April 1st 2011 to September 30th 2011. Only the features that are supported by ESO for P90 are given in this document. The bold font is used in the paragraphs of this document to put emphasis on the important facts regarding AMBER in P90 and should be considered by the reader.

1.2 What's new in this issue of the AMBER User Manual?

In this issue, we would like to remind:

- since P88 observations making use of FINITO have FINITO data recorded inside AMBER datafiles for purposes of *a* posteriori calibration (see 8);
- AMBER now has the capability to group-delay track (in visitor mode);
- limiting magnitudes at the UTs under very good conditions have been improved since P89;

And we would like to recall that: **the on-sky calibration should be preferably chosen as 'CAL-SCI-CAL' because of the intrinsic instability of AMBER transfer function.** Only programs interested in differential measurements will be allowed to have the simple 'CAL-SCI' calibration sequence.

The user should always consult the AMBER web pages at URL:
`http://www.eso.org/instruments/amber/` for the latests news.

1.3 On the contents of the AMBER User Manual

Section 2 of this manual is aimed at users who are not familiar with the AMBER instrument and who are interested in an **overview** of its capabilities. **Section 3** provides the **description of the instrument**: the instrument layout (Sect. 3.2), the expected performances (Sect. 2.5) and a reference to instrument features to be kept in mind while planning the observations or reducing the data (Sect. 4).

In **Section** 5, additional informations pertinent to observing with AMBER in P90 are presented. **Section** 6 provides the basic information needed to **prepare a program**. Finally, **Section** 8 present the current calibration plan of AMBER.

1.4 Contact Information

This document is evolving continually and needs to be updated and improved according to needs of the astronomers. All questions and suggestions should be channeled through the ESO User Support Department (email:`usd-help@eso.org` and homepage: `http://www.eso.org/org/dmd/usg/`).

The AMBER Home Page is found at the following URL:
`http://www.eso.org/instruments/amber/`.

Any user of the instrument should visit the web page on a regular basis to be informed about the current instrument status and developments.

2 Context

2.1 Is AMBER the right instrument for your program?

AMBER is a very high angular resolution instrument, far greater than any other ESO instrument. It also has some strong limitations, which one should be aware of, in order to make sure that AMBER is the right instrument for a given research program.

AMBER does not produce directly images. It combines three telescopes (3 ATs or 3 UTs) and forms interferometric fringes between each pair. Each fringe system is characterized by its contrast (also called visibility) and phase. These quantities are related to the brightness distribution of the object (the “image”). Moreover, AMBER disperses the light and thus offer spectroscopic and differential information, from multi band (simultaneous J, H and K) to emission/absorption line resolution (R$\sim$12000).

If your target has a characteristic size in the range 2-30 mas (milli arcsecond) and is brighter than K=9, then AMBER can probably bring you information any other ESO instrument can not.

2.2 AMBER and other VLT instruments

AMBER yields information at angular resolution scales between λ/B and λ/D, B being the telescopes separations (ranging from 16m to 130m) and D the diameters of the telescopes (8m for the UTs and 1.8m for the ATs). A single mode instrument like AMBER has no direct access to structures larger then λ/D. One might need in certain cases information at small spatial frequencies (*i.e.* larger scales) in order to complete the data collected with AMBER. The best-suited ESO instruments that can give access to these data are the NAOS/CONICA and SINFONI, which measure diffraction-limited images in the same wavelength domain as AMBER. With NAOS/CONICA it is possible to do both imaging and spectroscopy and SINFONI is unique in that it does full field spectroscopy in a 3” by 3” field. Further information on these instruments can be found at:
`http://www.eso.org/instruments/naco`.
and
`http://www.eso.org/instruments/sinfoni`.

The MIDI instrument is the other interferometric combiner at VLTI, and it operates with two telescopes in the N-band. AMBER and MIDI instruments use the same interferometric infrastructure, and many aspects regarding observing preparation and scheduling are very similar. More information on MIDI can be found at the following web address:
`http://www.eso.org/instruments/midi`.

2.3 Optical interferometry basics

The contrast and phase of the monochromatic fringes observed on a source with the given baseline B and wavelength λ yield the amplitude and phase of the Fourier transform of the source brightness distribution at the spatial frequencies $f = B/\lambda$. If this Fourier function is sufficiently sampled in the Fourier plane, then an inverse Fourier transform yields a model independent reconstruction of the image of the object at the wavelength λ with an angular resolution λ/B_{max}. There are two ways to obtain enough spatial information in order to assess the geometry of the source: 1) obtain data on different baselines triplets 2) rely of the natural "super synthesis" given by the spectral dispersion and the fact that AMBER records data simultaneously in many spectral channels.

Currently, most AMBER observations do not lead to reconstructed image, since it requires a very large quantity of data (hence a great amount of observing time). Not all programs need imaging, because the information provided by one AMBER single observation is already rich. There are different observables, which can be grouped as follow:

- the **visibility amplitude** is related to the object projected size along the projected baseline vector. The morphology of the object can therefore be retrieved through a modelling of the brightness distribution. Visibility will not be sensitive to non centro-symmetric brightness distributions.
- The phase is not directly measurable by AMBER. However, differential phase and closure phase (the phase of the so called bispectrum) are measurable. **The closure phase and and the differential phase are powerful tools to investigate asymmetry in the source geometry.**

It is important to note that the wavelength dispersion gives two completely different type of information. On the one hand, there is obvious **spectral information**, that allows to study emission lines, absorption lines, molecular absorption bands etc. On the other hand, the wavelength plays a role because **different wavelengths have different spatial resolutions** B/λ. In other words, the spectral dispersion helps to fill up the spatial frequency space (called also (u, v) plan, after the usual variables for the spatial frequencies). **One should constantly keep in mind these two complementary roles of the wavelength dispersion**.

AMBER is a beam combiner for three beams (the two beams combination is not offered) feeding the spectrograph and the camera working in the near infrared from 1 to 2.5 microns. It is a single mode instrument, which means that each baseline gives access to only one point in the frequency space per spectral channel. For this baseline, the instrument measures the following quantities for spectral resolutions of 35, 1500 and 12000 and a spectral coverage containing the K, H and J bands. :

- the **absolute visibility** in each spectral channel.

- the **differential visibility**, i.e. the ratio between the visibility in each spectral channel and the visibility in a reference spectral channel (average of several other channels for example).
- the **differential phase**, i.e. the difference between the phase in each spectral channel and the phase in a reference channel.
- the **closure phase** is the phase of the bispectrum computed in each spectral channel. The bispectrum is the complex product of three visibilities along a closed triangle. The closure phase is therefore theoretically equal to the sum of the three phases along the three baselines. This quantity is, to a great extent, independent from atmospheric perturbations.

2.3.1 Absolute visibility $V(f, \lambda)$

One visibility measurement for a single baseline can constrain the equivalent size of the source for an assumed morphology. Visibility measurements for several spatial frequencies (obtained through Earth rotation, different wavelengths, different telescopes combinations) constrain severely the models. The visibility should be carefully calibrated (see section 8).

2.3.2 Differential visibility $V(f, \lambda)/V(f, \lambda_0)$

In some cases, one is interested in variations of size of an target with the wavelength. This is the case when observing a structure which is present in a spectral line, whereas the continuum corresponds to an unresolved structure. One can then calibrate the measurement in the line by those in the continuum and the knowledge of the absolute visibility is not required, just the ratio between the visibility at a given wavelength and a reference channel.

Another possible application of the differential visibility if the study of objects with angular characteristic of the order of $\lambda^2/B\Delta\lambda$ ($\Delta\lambda$ is the wavelength range): the visibility will vary inside the recorded band due to the super-synthesis effect. This is, for example, a powerful tool to detect and characterize binary with separation $a \sim \lambda^2/B\Delta\lambda$.

2.3.3 Differential phase

Because the instrument is operated simultaneously at different wavelengths, one can measure variations of the phase with the wavelength. The principle is exactly the same as in astrometry, except that the reference is the source itself at a given wavelength. The most remarkable aspect of this phase variation is that it yields angular information on objects which can be much smaller than the interferometer resolution limit. These features come from the possibility to measure phase variations much smaller than 2π (i.e. 1λ). When the object is non resolved, the phase variation $\Phi(f, \lambda) - \Phi(f, \lambda_0)$ yields the variation with wavelength of the object photocenter $\epsilon(\lambda) - \epsilon(\lambda_0)$. This photocenter variation is a powerful tool to constrain the morphology and the kinematics of objects where spectral features result from large scale (relatively to the scale of the source) spatial features. Note that if this is attempted over large wavelength ranges the atmospheric effects have to be corrected in the data interpretation.

2.3.4 Closure phase

The closure phase, the sum of the phases of the 3 baselines inside a triangle, is independent from any atmospheric and instrumental phase offsets. It is therefore a very robust quantity in terms of calibration stability.

2.3.5 Image reconstruction

Image reconstruction consists in computing an approximation of the object brightness distribution out of the Fourier components measured by the interferometer. In order to get a meaningful image it is important to measure the maximum number of spatial frequencies in the (u, v) plane. This iterative procedure can be carried with several software tools that have been specifically developed for optical interferometry and take into account,among other things, the sparcity of the coverage and the lack of phase information. However the superiority of image reconstruction to model fitting can only appear with a significant paving of the (u, v) plane

In this manual we do no address the question of model fitting or image reconstruction. We focus on the description of AMBER operation and its interferometric observables extraction.

2.4 AMBER characteristics

The main characteristics of AMBER are summarized in Table 1.

2.5 AMBER typical performances

The following table shows the typical observables accuracies in good conditions (seeing of 0.8” with the UTs, 0.6” with the ATs, coherence time of 4ms or better), for targets at least 1 magnitude brighter than the limiting magnitudes and with a standard number of frames taken. Better performances can be obtained in better conditions or by stacking more frames (should be specifically asked), see foot notes [1,2,3,4] for exceptions. “NG” means not guaranteed.

mode	FINITO	calibrated V	diff. ϕ	CP
low HK	not used	10%	NG	5^{o}[1]
	coherencing	5%	NG	3^{o}[1]
	cophasing[4]	7%	NG	3^{o}[1]
medium K	coherencing	5%	2^{o}	4^{o}
	cophasing	5%	1^{o}	2^{o}
medium H	any mode[3]	5%	2^{o}[2]	4^{o}[2]
high K	cophasing	5%	1^{o}	2^{o}

[1] The closure phase error in low resolution is dominated by systematics, namelly a strong dependency of the closure phase with the piston (fringes’ phase shift, or OPD shift). We believe is is not possible to reach a better precision, even by stacking frames.

[2] The medium H band phase products suffer from systematics not understood at the moment.

[3] Usually, the use of the fringe tracker biases the calibrated visibility. The main source of bias when using the fringe tracker is when a jump of one fringe does not correspond to a jump of one fringe in the science channel. FINITO operates in the H band, hence AMBER H band data collected using FINITO in cophasing are much less biased than medium K data.

[4] The precision and accuracy of visibilities can be significantly increased by using *a posteriori* visibility calibration using FINITO recorded data.Technical tests in low spectral resolution mode with an excellent fringe tracking performance (cophasing) have shown that precisions as good as ≈ 1% on squared visibilities could be reached on bright targets. See 8 for a more detailed explanation.

As of P89 AMBER will have the ability, only used in visitor mode for the moment, to track the fringes in order to maintain optical path differences well within the coherence length. Technical validations have shown that, when the signal-to noise ratio of the interferometric measurements is sufficient, AMBER self-coherencing can improve the data quality significantly. While these numbers are to be taken with caution (good contitions, relatively bright sources, no extensive), the instrumental transfer function level is increased by several 10% and its stability improved. Closure phase accuracy is also significantly increased.

Proposals requiring performances better than these should state how they are going to be obtained (special calibration, large data set, etc).

Note that previous to P85, AMBER showed spurious fringing in HR-K, which was difficult to calibrate and led to degraded performances in this mode. A solution has been implemented to fix the problem: the performance of this mode are now similar to performances in MR-K.

3 AMBER overview

This section is a detailed description of AMBER.

3.1 AMBER principle

Figure 1 summarizes the key elements of the AMBER concept. A set of collimated and parallel beams are focused by a common optical element in a common Airy pattern which contains the fringes (-1- in Fig. 1). The spacing between the beams is selected for the Fourier transform of the fringe pattern to show separated fringe peaks. The Airy disk needs to be sampled by many pixels in the baseline direction (an average of 4 pixels in the narrowest fringe, i.e. at least 12 pixels in the baseline direction) while in the other direction only one pixel is sufficient. Each spectral channel is thus concentrated in a single column of pixels (-3- in Fig. 1) by cylindrical optics (-2- in Fig. 1). The fringes are dispersed by a standard "long slit" spectrograph (-4- in Fig. 1) on a two dimensional detector (-5- in Fig. 1). The spectrograph must be cooled down to about -60°C with a cold slit in the image plane and a cold pupil stop. In practice, it is simply cooled down to liquid nitrogen temperature.

High accuracy measurements require spatially filtered optical beams. The single way to achieve such filtering with decent light transmission is to use single mode optical fibers (-6-in Fig. 1). The flux transmitted by each filter must be monitored in real time in each spectral channel. This explains why a fraction of each beam is extracted and sent directly to the detector (-

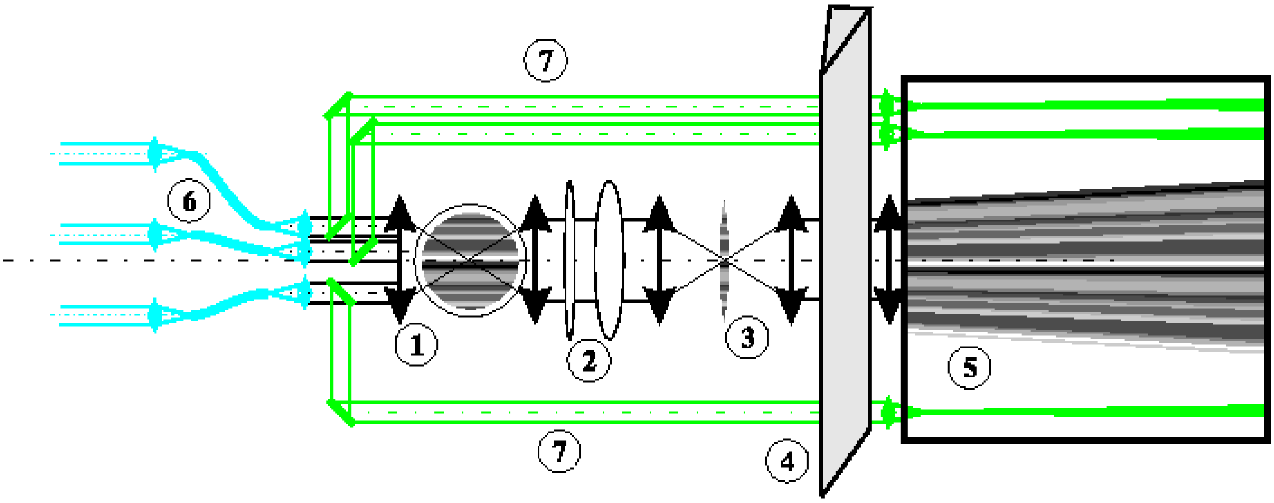

Figure 1: Basic concept of AMBER: (1) multi axial beam combiner. (2) cylindrical optics. (3) anamorphosed focal image with fringes. (4) "long slit spectrograph". (5) dispersed fringes on 2D detector. (6) spatial filter with single mode optical fibers. (7) photometric beams.

7- in Fig. 1). Before entering the fibers, the beams should be cleaned from the differential atmospheric refraction in the H and J bands or, in some cases, from one polarization.

3.2 AMBER layout

Figure 2 shows the global implementation of AMBER with the additional features needed by the actual operation of the instrument. The user can find more detailed information

3.2.1 Warm optics

The three spatial filter inputs (one for each spectral band) are separated by dichroic plates. For example the K band spatial filter (OPM-SFK) is fed by dichroic which reflect wavelengths higher than 2 μm and transmit the H and J bands.

After the fiber outputs, a symmetric cascade of dichroics combines the different bands again, but the output pupil in each band has a shape proportional to the central wavelength of the band. Therefore the Airy disk and the fringes have the same size for all central wavelength. This allows the same spectrograph achromatic optics to be used for all bands and the same sampling of all the central wavelengths to be operated.

Then the beams enter the cylindrical optics anamorphoser (OPM-ANS) before entering the spectrograph SPG through a periscope used to align the beam produced by the warm optics and the spectrograph.

3.2.2 Spectrograph

The spectrograph has an image plane cold stop, a wheel with cold pupil masks for 2 or 3 telescopes. The separation between the interferometric and photometric beams is performed in a pupil plane inside the spectrograph, after the image plane cold stop.

Table 1: AMBER characteristics

Description	Specification
Number of beams	Two or Three
Spectral coverage	JHK ($1 - 2.5\ \mu$m)
Spectral resolution in K	$\mathcal{R}$ ∼35 $\mathcal{R}$ ∼1500 $\mathcal{R}$ ∼12000
Spectral resolution in J & H	*same as in K*
Instrument contrast	0.8
Optical throughput	2% in K 1% in J and H
Detector size	1024 × 1024 detector array
Detector read-out noise	$11.37e^-$
Detector quantum efficiency	0.8
Observable	$V(f, \lambda)$, $V(f, \lambda)/V(f, \lambda_0)$, $\Phi(f, \lambda) - \Phi(f, \lambda_0)$, $\Phi_{123}(\lambda)$

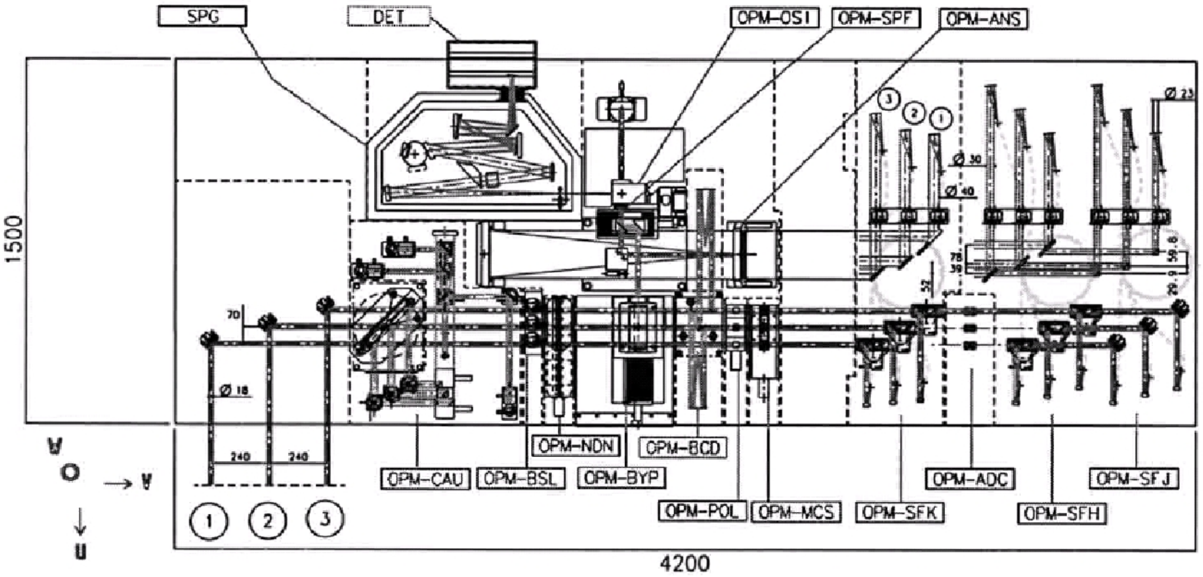

Figure 2: Amber global implementation

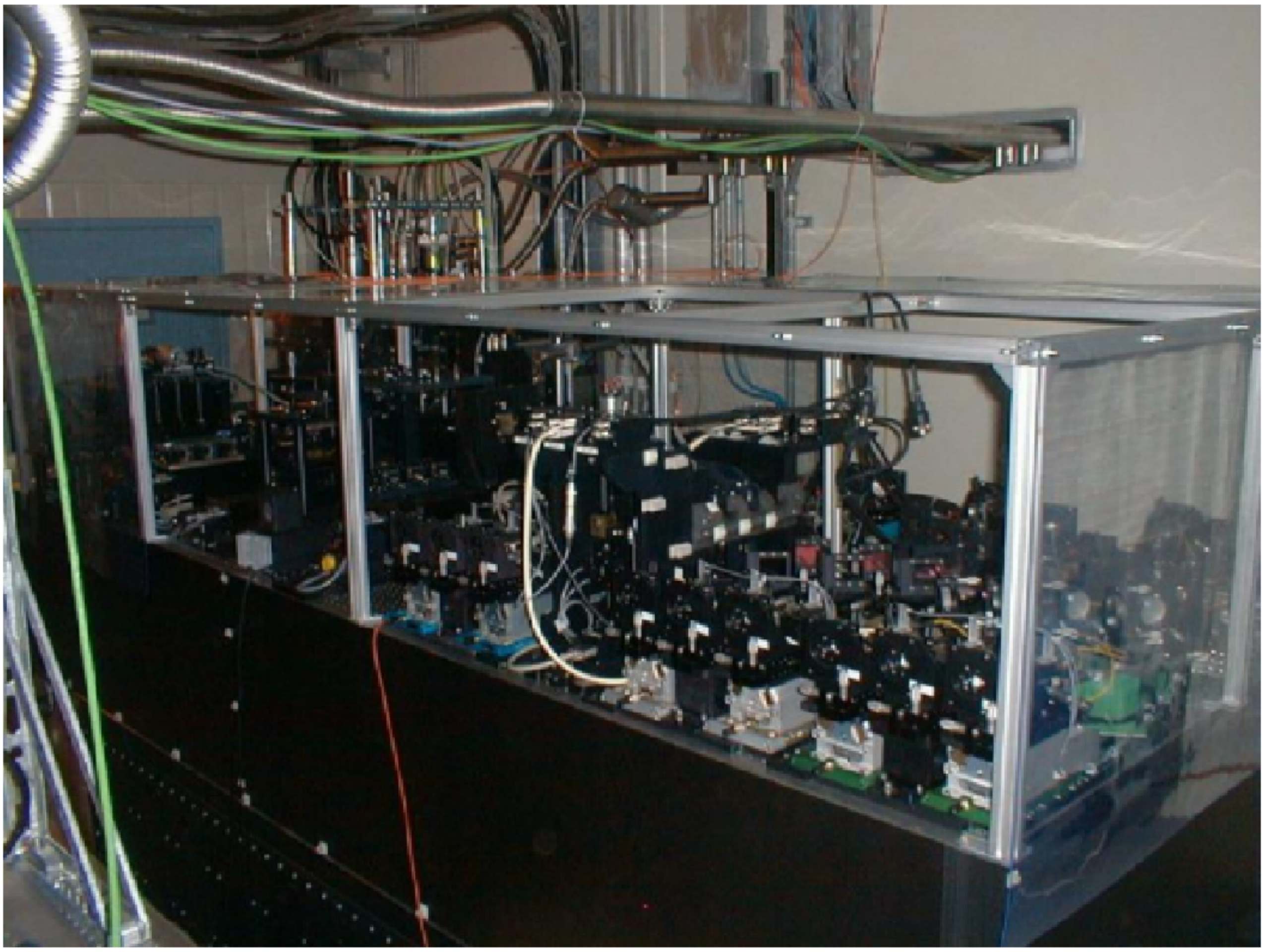

Figure 3: Photography of AMBER at Paranal

3.2.3 Detector

After dispersion, the spectrograph chamber sends the dispersed image on the detector chip (DET).

3.2.4 Calibration unit

The Calibration and Alignment Unit (OPM-CAU) emulate the VLTI for test and calibration purposes. The matrix calibration system (OPM-MCS) is set of plane parallel plates which can be introduced in the beam sent by the OPM-CAU in order to introduce the $\lambda/4$ delays in one beam necessary to calibrate the instrument.

To increase the instrument contrast, one polarization is eliminated by a polarization filter (OPM-POL) located after the dichroics.

3.3 From images to visibilities

The raw data produced by AMBER are images of the coherent overlap of the 3 beams dispersed by a prism (LR) or grisms (MR and HR). One get in addition 3 photometric outputs corresponding to each beam. An image of the detector image is displayed in Fig. 4.

The fringes are processed for each wavelength individually. The first action consists in separating the 3 fringes pattern apart. During the calibration, the fringes corresponding to each baseline is recorded. The interference term of the base ij is for the pixel k:

$$m_{ij}(k) = 2\sqrt{P_i P_j}\,\left(c_{ij}(k) V_{ij} \cos(\Phi_{ij}(k)) + d_{ij}(k) V_{ij} \sin(\Phi_{ij}(k))\right) \tag{1}$$

The quantities $c_{ij}(k)$ and $d_{ij}(k)$ are called the carrying waves and are displayed in Fig. 5. The interferogram (subtracted from photometry) can write: $i_{\mathrm{corr}}(k)$ as:

$$\begin{aligned} i_{\mathrm{corr}}(k) &= \sum_{j>i} m_{ij}(k) && (2)\\ &= M(k) \times C && (3) \end{aligned}$$

where C is a vector of the values $(R_{ij},\ I_{ij})$ corresponding respectively to the real- and imaginary-part of the correlated flux $2\sqrt{P_i P_j}\,V_{ij}$ for all baselines and $M(k)$ is a matrix with the values of the carrying waves $c_{ij}(k)$ and $d_{ij}(k)$. The matrix $M(k)$ is the so-called pixel-to-visibility matrix (P2VM). The AMBER internal calibration process consists into measuring this P2VM.

The P2VM calibration procedure occurs every time that we change the instrumental setup. The P2VM observation is automatically included in the standard templates and thus requires no input or configuration by the observer.

4 Instrument features and problems to be aware of

The following caveats and limitations should be taken into consideration:

- Vibrations have been found in the VLTI arm which have been partially fixed. Residual vibrations may still exist in particular on the UTs. It prevents from getting stable transfer function. Absolute calibration of the visibility is much better on the ATs.

- When FINITO is used, for any given spectral mode the full spectral range can be read out on the detector. If due to airmass or other constraints FINITO cannot be used then the spectral coverage can be severely limited to a dozen of pixels on the UTs.
- The closure phase error in low resolution is dominated by some not understood systematics. We believe it is not possible to reach a better precision even by stacking frames.
- Medium resolution H band data suffer from systematics in the phases, not understood at the moment.
- High resolution K Band data suffer residual fringing in the phases. This limits the ultimate precision in this mode. A solution is being implemented to resolve this optical problem.

Fast optical path difference fluctuations due to vibrations and atmosphere lead to:

- a decreased instrument contrast;
- a degraded instrumental contrast stability and therefore a degraded final precision and accuracy of calibrated visibility;

For that purpose, when FINITO is used as a fringe tracker, the fringe tracking data is now recorded to allow post-processing of AMBER visibilities.

5 AMBER in P90

Several modes are still under development and waiting in-depth investigations before being offered. In P90 the modes offered will be the High Resolution K band (HR-K), Medium Resolution K band (MR-K) and H band (MR-H), and the low resolution K and H bands (LR-HK), with a spectral resolution $\lambda/\Delta\lambda$ of approximately 12000, 1500 and 35, respectively.

In LR-HK mode, the K band will be acquired simultaneously with the H band. IRIS which is always used is taking 25% of the K-band flux. If FINITO is used , it will use 70% of the H band flux.

Since P83, FINITO is now part of the standard mode in HR-K and MR-K. This rule also applies to MR-H as of P84. **Any proposal asking not to use FINITO in these modes should properly explain the reason why and require a waiver.** FINITO fringe tracking information will be recorded with AMBER data (see section 8 for an explanation).

As of P89, and only in visitor mode the first period, a *self-coherencing* mode is operational. AMBER will have the capability, by measuring the optical path difference from its fringes, to send a correction to the delay line in order to better maintain the fringes within coherence length. This will result in an increased and more stable instrumental contrast together will less dispersed closure phase.

See the AMBER instrument webpage:
`http://www.eso.org/instruments/amber/inst/`
for the most recent information on the exact wavelength ranges and section 6.2.1 for the configuration options for the spectrograph.

5.1 Service and Visitor Modes

For P90 , AMBER is offered in service mode and in visitor mode (see Sect. 10). During all the period, the unique contact point at ESO for the user will be the User Support Department (`email:usd-help@eso.org` and homepage:
`http://www.eso.org/org/dmd/usg/`).

The visitor mode is more likely to be offered for proposals requiring non-standard observation procedures. The OPC will decide whether a proposal should be observed in SM or VM. As for any other instrument, ESO reserves the right to transfer visitor programs to service and vice-versa.

6 Preparing the observations

Proposals should be submitted through the ESOFORM. Carefully read the following information before submitting a proposal, as well as the ESOFORM user manual. The ESOFORM package can be downloaded from:
`http://www.eso.org/observing/proposals/`
Considering a target which has a scientific interest, the first thing to do is to determine whether this target can be observed with AMBER or not.

Please note that the limiting magnitudes for AMBER observations depend on the seeing and sky transparency, and that appropriate weather conditions have to requested in the Phase 1 proposal.The details of the current magnitude limits can be found at the AMBER instrument webpage:
`http://www.eso.org/instruments/amber/inst/`

6.1 Proposal guidelines

For general information about the VLTI facility, please refer to the VLTI User Manual.

6.1.1 Guaranteed time observation objects

Check any scientific target against the list of guaranteed time observation (GTO) objects. This guaranteed time period covers the full P90 . Make sure the target has not been reserved already. The list of GTO objects can be downloaded from:
`http://www.eso.org/sci/observing/visas/gto/index.html`

6.1.2 Time critical, combination of triplets

For successful observations in either service or visitor mode, it is very important that special scheduling constraints such as the combination of different triplets within a certain time range or other time-critical aspects are entered in Box 13 'Scheduling Requirements'. The proposal should also be marked as time critical (see the ESOFORM package for details).

6.1.3 Calibrator Stars

The user should use appropriate calibrator stars in terms of target proximity, magnitude and apparent diameter. It should be provided by the user with the submission of the Phase2 material. To help the user to select a calibrator, a tool called "`CalVin`" is provided by ESO `http://www.eso.org/observing/etc/`

Two calibration sequences are offered in service-mode: SCI-CAL (first science then calibrator) is reserved to program only requesting differential quantities. CAL-SCI-CAL (science bracketed by calibration) is mandatory for any program requesting absolute calibration and **therefore is the default mode**. Further details can be found in Section 8.

6.1.4 Field of View

AMBER is a single-mode instrument and therefore the field of view (FoV) is limited to the Airy disk of each individual aperture, i.e. 250 mas for the ATs in K and 60 mas for the UTs in K. For most observations this will not have consequences but can be limiting to observations of objects that consists of several components *e.g* binaries, stars with disk and/or winds, etc that have a spatial extension equal or superior than the interferometric FoV. While such observations are not impossible the observer will have to take into account this incoherent flux contribution in his data analysis.

6.1.5 Complex fields

When observing complex fields within a few arcseconds, it is necessary that MACAO/STRAP behaves very well in order to disentangle the desired object from others (see VLTI Users Manual for seeing and limiting magnitude of STRAP/MACAO). However, for fields with several objects within 1 to 3 arcseconds it is not guaranteed that MACAO will perform properly. It is therefore recommended to use a guide star in this situation.

For fields with objects with separations less than an arcsecond MACAO will resolve the objects down to ~0.1-0.15 arcsec. For separations smaller than ~0.3 arcsec, it cannot be guaranteed that the proper target has been injected into the fiber. These acquisitions have to follow a non-standard extensive procedure and require the presence of the PI in Visitor Mode.

6.1.6 Bright objects

In Low Resolution observations (LR) of very bright objects ($K_{\mathrm{mag}} < 0$), the detector can saturate even when using Neutral density filters during excellent weather conditions. The user should consult the webpages for the latest information on the magnitude limits. If possible the user should try to use the MR spectral configuration if the scientific goals still can be achieved in this mode.

6.2 Choice of the AMBER configuration

6.2.1 Instrument set-up

The instrument set-up is defined by the spectral configuration of the instrument and the 3T configuration.

Any change of the spectral configuration requires an internal calibration, i.e. spectral calibration and P2VM calibration. This is automatically taken care of by the internal calibration plan and no action or setups are needed from the user. Note that only one spectral configuration is allowed in one OB.

Any change of the neutral densities, the ADC, the position of the fiber heads, i.e. all elements located before the spatial filters does not require internal calibrations. They can be used or not depending on the source characteristics.

6.2.2 Observing modes

Without FINITO, only fixed DITs of 25, 50, or 100 ms (ATs only) are offered. With FINITO longer DITs are available.

In MR-K and HR-K, the choice of short DIT restrict the width of the central band. The user should check the AMBER Template Manual and the AMBER webpages for further information.

The details on the exact wavelength ranges, DITs, and central wavelengths available can be found on the AMBER Instrument webpage `http://www.eso.org/instruments/amber/index.html`.

7 Introducing Observation Blocks (OBs)

For general VLT instruments, an **Observation Block (OB)** is a logical unit specifying the telescope, instrument and detector parameters and actions needed to obtain a **single** observation. It is the smallest schedulable entity which means that the execution of an OB is normally not interrupted as soon as the target has been acquired. An OB is executed only once; when identical observation sequences are required (*e.g.* repeated observations using the same instrument setting, but different targets or at different times), a series of OBs must be constructed.

Because an OB can contain only one target, science and associated calibration stars (cf. Sect. 8) should be provided as two different OBs. Thus each science object OB should be accompanied by a calibrator OB. These OBs should be identical in instrument setup, having only different target coordinates.

Moreover with single-telescope instruments, any OB can be performed during the night. In the case of interferometric instrument, the instant of observation define the location of the observation in the (u, v) plan.

7.1 Standard observation (`OBS_Std`)

The same exposure cycle can be used for two or three telescopes (currently only three telescope configurations are offered). The correction of instrumental biases is based on the use of a reference star and the sequence of operations is as presented in Fig. 6.

7.1.1 Observing cycle

A standard observation with AMBER in P90 can be split in the several sub tasks:

1. Configuration: Setup of the desired spectral resolution, wavelength range and DIT.

2. Internal calibration of the chosen instrument configuration (P2VM) see sec. 3.2.4.
3. Acquisition: Slew telescopes to target position on sky, and slew the delay-lines to the expected zero-OPD position.
4. As stated in VLTI User Manual, the user has the possibility to use a guide star for the Coude systems, different from the target. Refer to this manual for the limitations of this option.
5. Fringe Search: Search the optical path length (OPL) offset of the tracking delay-lines yielding fringes on AMBER (actual zero-OPD), by OPD scans at different offsets. When fringes are found the atmospheric piston is calculated and the OPL offsets corresponding to zero-OPD are applied.
6. If FINITO is used the above step is performed by FINITO and not by AMBER.
7. Observations: Start to record data of interest with suitable DIT. In P90 it is foreseen to only use DITs of 25 ms or 50 ms for standard absolute phase observations, and DITs of 100 ms for differential phase observations. The longer DIT allows a larger wavelength range in MR-K, MR-H or HR-K observations.
8. If FINITO is used longer DITs are available.

7.2 Computing time overheads for added bands

One OB is executed in 20 minutes in LR mode, and 25 minutes in MR or HR modes, and this for one spectral band. Additional spectral bands (up to 2) take 15 minutes each. Hence, the default CAL-SCI-CAL sequence requires 60min (3 OBs) in LR and 75 min in MR or HR; the CAL-SCI sequence requires 40min (2 OBs) in LR and 50 minutes in MR and HR. Again, this applies for one spectral setting.

Users interested in several spectral positions should add 15 minutes for each additional spectral band per OB. Similarly, user interested in repeating the same spectral band to obtain more frames should add 15 min per OB. A maximum of 2 additional bands per observation (*i.e.* per OB) is allowed.

8 Calibration Plan

8.1 Data products

The observatory shall provide the following calibrations to science (SCI) or calibrator stars (CAL) data:

1. daily: darks obtained with the same DITs as the data. 2 different types of darks are provided (see below).
2. daily: sky obtained with the same DITs as data, taken right after the ”on target” data.
3. daily: ”Pixel to Visibility matrix” (P2VM) for all observations. All pairs SCI-CAL or triplet CAL-SCI-CAL should be taken with the same P2VM, taken prior to the sequence. The validity of the P2VM is 6 hours.

4. at period change or any instrument intervention: "bad-pixel" and "flat-field" maps.

8.2 Dark frames

We provide two different types of dark frames: 'cold' and 'warm' darks. Cold darks are taken by closing the spectrograph with a cold metallic patch, so the detector sees an element at the temperature of the cryostat. Conversely warm darks are taken by closing shutters outside of the cryostat, hence there will be a residual of thermal emission (especially at longest wavelengths).

Warm darks are taken right before the observations, whereas cold darks are taken the following morning. The reason why the cold darks cannot be taken simultaneously is because the cold patch is on the same wheel as the spectrograph slit. Hence, taking cold darks for every observations is not possible without moving the grism wheel every time. This is why cold darks are taken in the morning.

It is recommended to use 'cold darks' and 'sky' for the actual data reduction. 'Warm darks' are currently kept for consistency with the previous observation procedure.

8.3 Calibrator stars

Calibrator stars are stars with known angular diameters, yielding to the highest possible visibility, knowing that:

- fringes' SNR should be comparable between SCI and CAL.
- CAL should be as close as possible to SCI (ideally $\leq$ 25deg and similar airmass).
- CAL should be observable one hour before AND one hour after the SCI target. This is to ensure that it can be observed after or before the SCI if the later has been observed at the limit of it LST constraint. In the case of bracketted observations (i.e CAL-SCI-CAL) and impossibility to find a calibrator observable before and after a second calibrator should be used.

Considering that the choice of calibrator can be tailored to the actual specificities of the scientific goal, the users are responsible for the choice of their calibrators, and the creation of the subsequent OBs. ESO offers the CalVin tool[1] to chose the calibrator stars.

The observation of calibrator stars are used to measure the transfer function of the instrument, namely:

- visibility transfer function: $V^2_{\rm inst} = (V^2_{\rm measured}/V^2_{\rm expected})_{\rm CAL}$ the calibrated visibility is estimated by: $V^2 = (V^2_{\rm measured})_{\rm SCI}/V^2_{\rm inst}$.
- phase closure transfer function: $CP_{\rm inst} = (CP_{\rm measured} - CP_{\rm expected})_{\rm CAL}$ the calibrated phase closure is estimated by: $CP = (CP_{\rm measured}) - CP_{\rm inst}$.

Other quantities can be calibrated, for example the chromatic phase dispersion. The chromatic phase dispersion is a function of the air path between each pair of telescopes. With many CAL at different DL stroke, one can compute a polynomial fit to the differential phase and extrapolate the polynomials coefficients as a function of air path difference.

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[1] `http://www.eso.org/observing/etc/`

All calibrator stars observation (`DPR.CATG='CAL'`) are made public by ESO, so users can retrieve all calibrators taken in a given night in order to refine their estimation of the transfer function.

Sequence CAL-SCI-CAL should be used if absolute products will be used: this is the most common case. Some particular programs only require differential interpretation: users should use the SCI-CAL sequence for this special programs.

8.4 FINITO fringe tracking information

Even during the shortest AMBER integration times (25 ms) and with FINITO operating correctly the random optical path fluctuations (jitter) have sufficient amplitude to lead to 1) a contrast decrease (therefore a bias) and 2) an unstability of the visibility transfer function. Both linked phenomenon contribute to a significant decrease of AMBER performances.

During one AMBER frame acquisition residual fringe motion reduces the fringe contrast by a factor $\exp(-\sigma_\phi^2)$ where σ_ϕ is the fringe phase standard deviation over the frame acquisition time. Therefore, since the jitter varies with time, this attenuation factor is unfortunately not stable and there is a high probably that data taken several minutes later on the calibrator, will not allow to cancel the term and will result in final biased visibilities.

Since FINITO measures fringe phase several times during one AMBER frame acquisition (typical integration time is of the order of 1ms) it provides a way to compute a contemporaneous estimation of the attenuation factor.Therefore an *a posteriori* frame to frame correction is possible.

The commissioning of the VLTI Reflective Memory Network Recorder (RMNrec) in February 2008 has made possible to store the real-time FINITO, OPDC (Optical Path Difference Controller Machine) and Delay Lines data into proper FITS files. Preliminary results published by Lebouquin et al. (SPIE 2008,7013, p33, Schöller et al. eds.) have shown encouraging perspectives for AMBER data post-processing using FINITO data. These results have been confirmed by technical tests which have shown the possibility for a very significant increase in visibility precision and have motivated the decision to include FINITO data within AMBER data. However the reader should be warned that performant corrections can only be reached if FINITO performs well (cophasing) i.e if the source is bright and not too resolved. Also it is important to note that the latest version of the amdlib pipeline (3.0) does not include the post-processing. This correction is therefore left to the observer. Further testing will be carried in the future to better constrain the observational specifications requested to obtain good results.

8.5 AMBER self-coherencing information

AMBER fringes on the detector appear as luminous stripes. They are vertical if the optical path is equalized and inclined in the opposite case. At each frame acquisition a quicklook software extracts the main observables from the data: the fringes amplitude, signal to noise and piston etc. Until P89 AMBER did not use the piston information. Yet it provided a way to estimate the optical path difference. The possibility to improve the phasing on the telescopes only relied on the capability to observe with FINITO. AMBER can now, when FINITO cannot be used, and when the signal to noise is sufficient, extract an optical path correction from the data and send it to the delay lines. Since in AMBER the observables (visibility and closure phase) depend on the performance of this **coherencing** (also known as “group-delay tracking”) the data quality is significantly improved (depending on the signal-to-noise of the data). This mode will only be offered in visitor mode for period 90 and its final efficiency will be assessed prior to its generalization for all service and visitor observations. This operating mode can be desactivated upon request by the visitor.

9 Bibliography

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- *The Very Large Telescope Interferometer - Challenges for the Future*, Astrophysics and Space Science vol 286, editors: Paulo J.V. Garcia, Andreas Glindemann, Thomas Henning, Fabien Malbet; November 2003, ISBN 1-4020-1518-6.

- *Observing with the VLT Interferometer*, Wittkowski et al., March 2005, The Messenger 119, p14-17

- reference documents (templates, calibration plan, maintenance manual, science/technical operation plan), especially **VLT-MAN-ESO-15000-4552**, the VLTI User Manual.

10 Glossary

Constraint Set (CS): List of requirements for the conditions of the observation that is given inside an OB. OBs are only executed under this set of minimum conditions.

Observation Block (OB): An Observation Block is the smallest schedulable entity for the VLT. It consists of a sequence of Templates. Usually, one Observation Block include one target acquisition and one or several templates for exposures.

Observation Description (OD): A sequence of templates used to specify the observing sequences within one or more OBs.

Proposal Preparation and Submission (Phase-I): The Phase-I begins right after the Call-for-Proposal (CfP) and ends at the deadline for CfP. During this period the potential users are invited to prepare and submit scientific proposals. For more information,
`http://www.eso.org/observing/proposals.index.html`

Phase-II Proposal Preparation (P2PP): Once proposals have been approved by the ESO Observation Program Committee (OPC), users are notified and the Phase-II begins. In this phase, users are requested to prepare their accepted proposals in the form of OBs, and to submit them by Internet (in case of Service-mode). The software tool used to build OBs is called the P2PP tool. It is distributed by ESO, and can be installed on the personal computer of the user.
See http://www.eso.org/observing/p2pp/

Service Mode (SM): In Service Mode (opposite of the Visitor-Mode), the observations are carried out by the ESO Paranal Science-Operation staff (PSO) alone. Observations can be done at any time during the period, depending on the CS given by the user. OBs are put into a queue schedule in OT which later send OBs to the instrument.

Template: A template is a sequence of operations to be executed by the instrument. The observation software of an instrument dispatches commands written in templates not only to instrument modules that control its motors and the detector, but also to the telescopes and VLTI sub-systems.

Template signature file (TSF): File which contains template input parameters.

Visitor Mode (VM): The classic observation mode. The user is on-site to supervise his/her program execution.

11 Acronyms and Abbreviations

AD:	Applicable document
AMBER:	Astronomical Multi-BEam Recombiner
AO:	Adaptive optics
AT:	Auxiliary telescope (1.8m)
CfP:	Call for proposals
CP:	Closure Phase
CS:	Constrain set
DI:	Differential Interferometry
DIT:	Detector Integration Time
DDL:	Differential Delay line
DL:	Delay line
DRS:	Data Reduction Software
ESO:	European Southern Observatory
ETC:	Exposure Time Calculator
FINITO:	VLTI fringe tracker
FT:	Fringe tracker
IRIS:	InfraRed Image Stabiliser
LR:	Low Resolution
LST:	Local Sideral Time
MACAO:	Multiple Application Curvature Adaptive Optics
MR:	Medium Resolution
MIDI:	MID-infrared Interferometric instrument
MIR:	Mid-InfraRed [5-20 microns]
NDIT:	Number of individual Detector Integration
NIR:	Near-InfraRed [1-5 microns]
OD:	Observation Description
OB:	Observation Block
OT:	Observation Toolkit
OPC:	Observation Program Committee
OPD:	Optical path difference
OPL:	Optical path length
Phase-I:	Proposal Preparation and Submission
P2PP:	Phase-II Proposal Preparation
QC:	Quality Control
REF:	Reference documents
SM:	Service Mode
SNR:	Signal-to-noise ratio
STRAP:	System for Tip-tilt Removal with Avalanche Photo-diodes
TBC:	To be confirmed
TBD:	To be defined
TSF:	Template Signature File
UT:	Unit telescope (8m)
VIMA:	VLTI Main Array (array of 4 UTs)
VINCI:	VLT INterferometric Commissioning Instrument
VISA:	VLTI Sub Array (array of ATs)
VLT:	Very Large Telescope
VLTI:	Very Large Telescope Interferometer
VM:	Visitor mode

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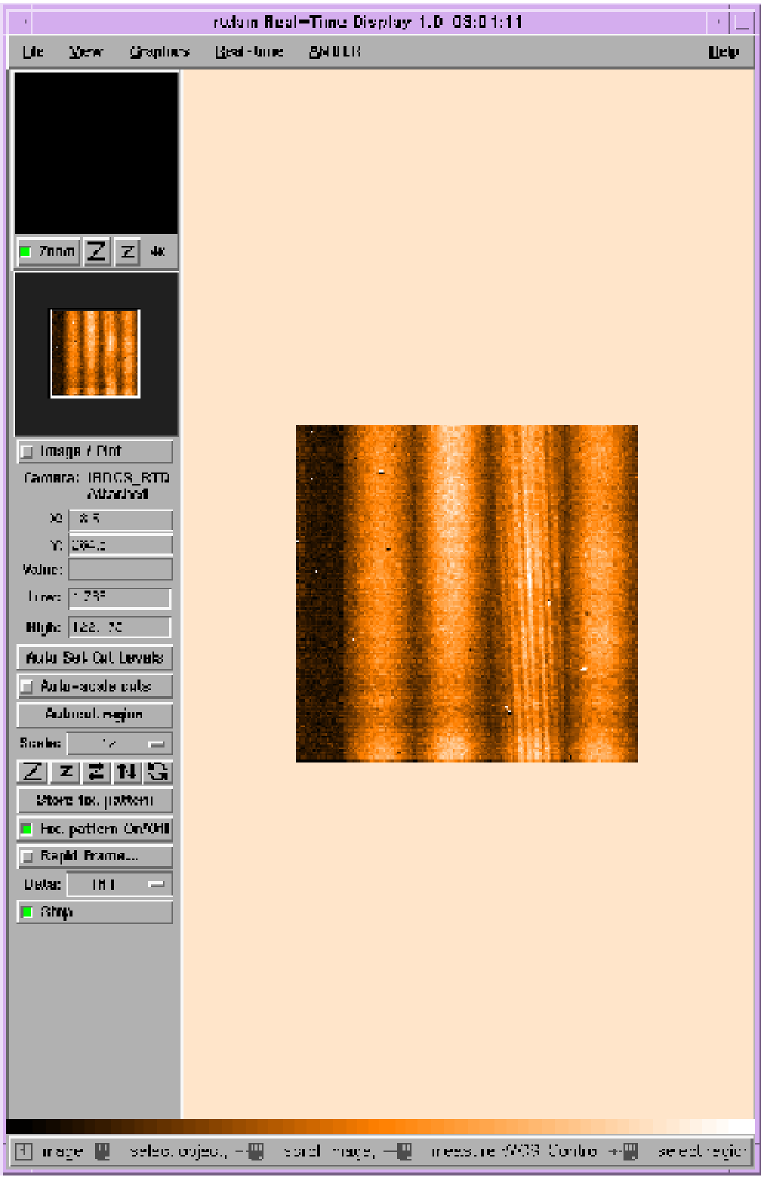

Figure 4: Image of the fringes recorded by AMBER in medium resolution around 2.1 microns using an artificial light-source. The wide stripes are the photometric spectrum of the 3 beams and the band with narrow stripes is the interferometric channel with the fringes.

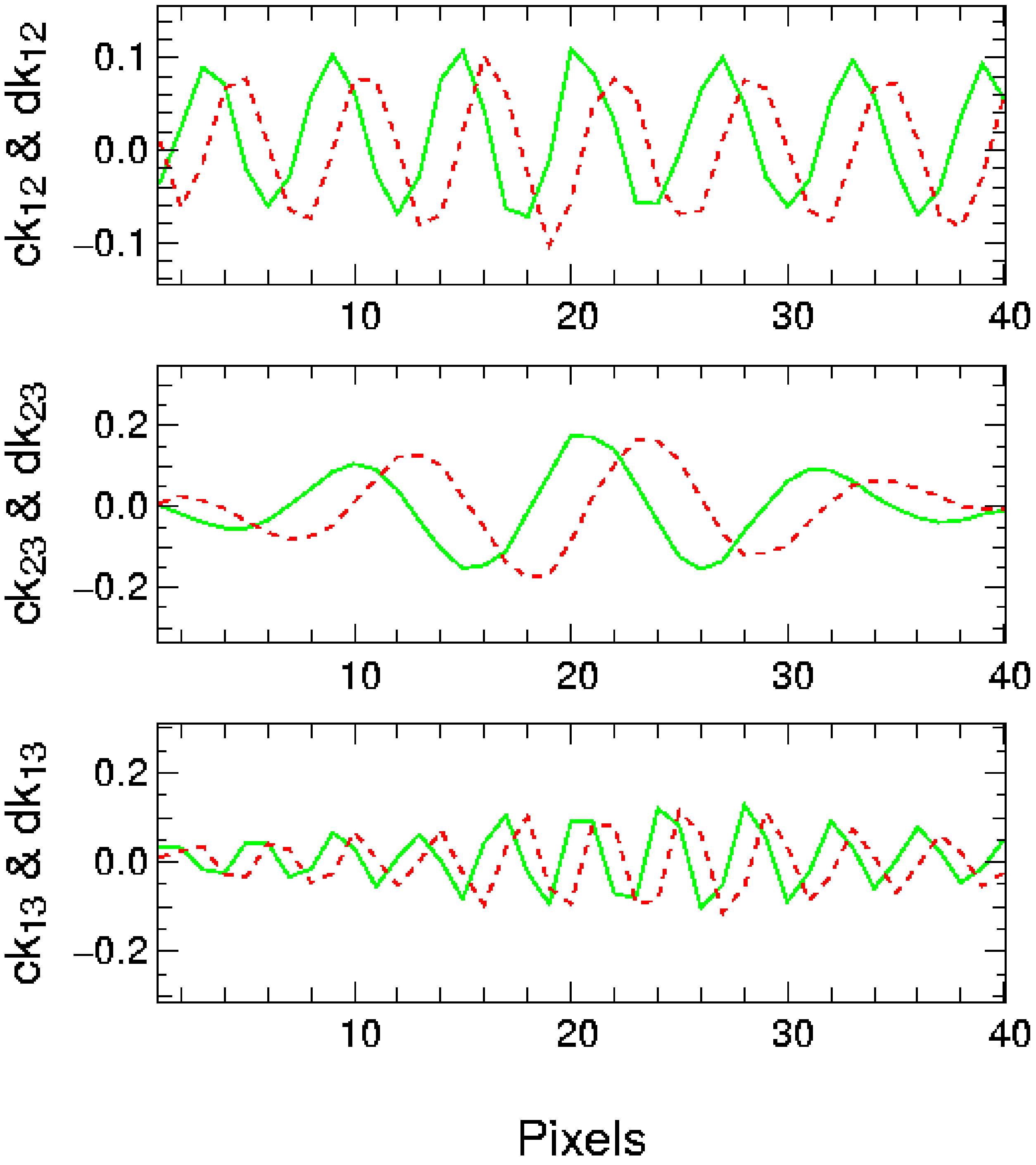

Figure 5: Example of carrying wave $c(k)$ (solid green line) and $d(k)$ (dashed red line).

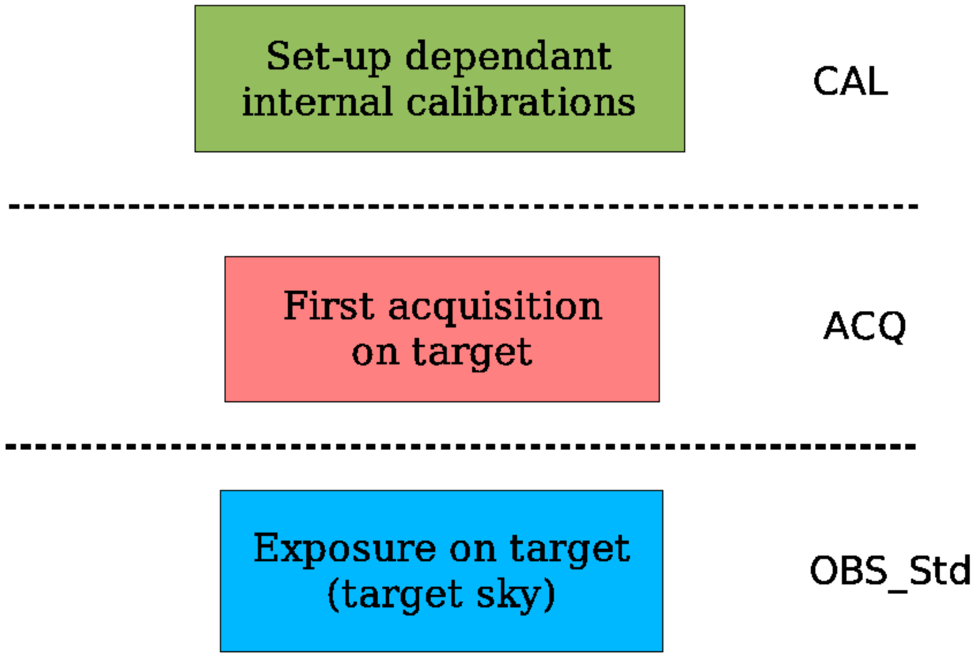

Figure 6: Standard observation mode (`Std`).