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Very Large Telescope

Paranal Science Operations

AMBER User Manual

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Contents

1 INTRODUCTION

AMBER, the near-infrared/red focal instrument of the VLTI, operates in the J, H, and K bands (ie 1.0 to 2.4 μm). The instrument has been designed to be used with two or three beams, thus enabling also the use of closure phase techniques. The magnitude limits of AMBER are K=7 with Low Resolution (LR-HK) on UTs and K=5.1 on the ATs without the external fringe tracker (FINITO). It is possible to reach K=7 (H=7) in LR-JHK and MR-K and K=7 (H=6) in HR-K, for seeing better than 0.8 arcsec. FINITO on the ATs has been offered since P80 and the current limiting magnitudes are K=5 in all modes *i.e.* for LR-KH, MR-K and HR-K, for seeing less than 0.6 arcsec. Note that the medium and high resolution modes are no longer offered without FINITO in standard mode. A waiver should be submitted if the proposal requires FINITO not to be used. See also this URL for the current requirements:
`http://www.eso.org/instruments/amber/inst/`

1.1 Scope of this manual

This document summarizes the features and possibilities of the Astronomical Multi-BEam combineR (AMBER) of the VLT, as it will be offered to astronomers for the six-month ESO observation period number 83 (P83), running from October 1st 2008 to March 31st 2009. Only the features that are supported by ESO for P83 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 P83 and should be considered by the reader.

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

In P83 there are slight updates to the limiting magnitudes depending on the seeing conditions. The user should consult the AMBER web pages at URL:
`http://www.eso.org/instruments/amber/`.

1.3 Acknowledgments

The editor thanks Fabien Malbet (LAOG, Grenoble) who delivered the document which formed the first first version of this manual in February 2005. The editor also thanks Markus Wittkowski at ESO-Garching for his comments and Stephane Brillant, Stan Stefl and Jean-Baptiste Lebouquin, in Paranal for their comments.

1.4 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** describes the AMBER instrument within the VLTI framework, and **section 4** provides the **description of the instrument**: the instrument layout (Sect. 4.2), the expected performances (Sect. 4.4) and a reference to instrument features to be kept in mind while planning the observations or reducing the data (Sect. 5). It can be consulted by users who want to prepare an *Observing Proposal*

(Phase I), but should definitively be read by those who have been granted observing time and have to prepare their observations (Phase II). In **Section 6** I present some added information pertinent to observing with AMBER in P83 . **Section 7** provides the basic information needed to **prepare a program**: the configuration of the VLTI (Sect. 7.1), the identification of the observing modes and of the standard settings (Sect. 7.2).

1.5 Contact Information

The aim of this manual is to make the users acquainted with the AMBER instrument before writing proposals. In particular, sections 1, 2, 3, 4 and 4.3 are aimed at astronomers not used to interferometric observations. 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 Capabilities of the instrument

What follows is not intended to be perfectly accurate from a mathematical point of view but to remind what is accessible in practice. In principle the contrast and phase of the 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}.

Besides the sensitivity limits, two classes of problems make this imaging process quite difficult.

- First calibrating the measurements, i.e. deducing the object visibility and phase from the fringes contrast and position.
- Second, making measurements at a sufficiently sampled Fourier plane can be time-consuming.

This is why, although making images will actually be the goal of AMBER on the VLTI in some cases, it is worth examining what kind of astrophysical information can be extracted from any individual AMBER measurement for a given baseline configuration.

2.1 What measures AMBER?

AMBER is a beam combiner for up to three beams 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 give access to only one point in the frequency space per spectral channel. For this baseline, the instrument is designed to measure:

– the **absolute visibility** in each spectral channel.
– the **relative 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 **phase difference**, i.e. the difference between the phase in each spectral channel and the phase in a reference channel. This is the main purpose of **Differential Phase** observations.
– the **closure phase** when used with three beams.

for the following spectral resolutions: 35, 1500 and 12000 and a spectral coverage containing the K, H and J bands.

The scope of this manual is limited to the measure and calibration of single (or triplets) (u, v) points and do not address the use these measurements to constrain astrophysical models or the image reconstruction process.

2.2 Science accessible with the different observables

Thanks to the combination of instrument performance, choice of baselines, closure phase capability, and the photon-collecting power of the VLTI, a wide range of astronomical sources can be targeted. What follows is a brief presentation of the major objectives, which are in no way a full listing of all scientific possibilities of the instrument. Most of these objectives need the PRIMA (astrometry, fringe stabilizer, and dual feed) facility or FINITO (fringe tracker) to realise the objectives to their full extent, but even without these, AMBER will be able to make great advances in several areas including the following ones:

- Hot extrasolar planets: Determination of planetary mass, orbital parameters and the spectra of the planet and the star.
- Active Galactic Nuclei: to spatially resolve the Broad Line Region and to constrain its geometry and kinematics. The ionized disks around the putative Massive Black Hole can be studied to constrain its morphology, size, and, velocity and density field. Measuring the wavelength dependence of the central point source, the shape and size of circumnuclear dust structures as well as additional structures (e.g., the inner region of jets, circumnuclear starburst regions, or bars) in order to test AGN models.
- Circumstellar material in hot/cold and young/old stars: Constraints on the size and morphology of the disk, including velocity and density fields. Similarly, jets and bipolar outflows can be studied, obtaining sizes, morphology, and, velocity and density fields.
- Binaries: Direct measurement of actual orbital motions, and the masses of the stars.
- Stellar structure: Measurements of the radius, ellipticity, surface activity, and, limb-darkening effects.

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

If the source is bright or if a bright reference star is close enough, it is possible to obtain an unbiased estimate of the source visibility amplitude from the fringe contrast. A visibility measure for a single baseline can constrain the equivalent size of the source for an assumed morphology. Visibility measures for several spatial frequencies (obtained through Earth rotation, different wavelength, different baseline) constrain severely the models. However the interpretation of the results remains always model dependent. Different images can lead to similar visibilities and discriminating between models usually requires measurements of high accuracy.

In general, the phase of fringes cannot be related to the phase of the source Fourier transform because of the atmospheric phase jitter. Only relative phase measurements are possible for sufficiently close spectral bands. This can be extended to spectral bands further away using a correct model of the atmospheric effects, but this is out of the scope of the standard data reduction.

2.2.2 Relative visibility $V(f,\lambda)/V(f,\lambda_0)$

In some cases, one is interested in variations of the target spatial intensity distribution 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.

2.2.3 Relative phase variation with wavelength

If the instrument is operated simultaneously at different wavelengths, then 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 accurately phase variations much smaller than 2π. 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 reduction.

2.2.4 Closure phase and phase reconstruction

If fringes are present at all three baselines and the fringes for all baselines are analyzed simultaneously, then we obtain a relation called closure phase. The closure phase relations are independent from any antenna-based atmospheric or instrumental phase offsets affecting the beams before arriving to the telescopes. If all spatial frequencies have their phases in partially redundant closure phase relations, an iterative algorithm allows to compute all phases step by step. Then it is therefore possible to reconstruct the image if the (u,v) plane is well filled or to constrain the models if only some closure phases are available.

2.3 AMBER characteristics

The main capabilities of AMBER are summarized in Table 1. It should be noted that the *Instrument Visibility Accuracy* in the table only reflects the current status of the instrument and is expected to improve in the coming periods.

3 AMBER within the VLT interferometer

3.1 VLTI infrastructure

AMBER is the final stage of an overall infrastructure. It is part of a VLTI well defined plan. The general concept of the VLTI is to provide an interferometric focus to the instruments, like modern telescopes provide almost diffraction-limited beams to their instruments. Therefore the VLTI infrastructure works like a general facility which supplies the following functions:

- Sampling of the (u, v) plane with 4 fixed Unit Telescopes (UTs) and 4 movable Auxiliary Telescopes (ATs) with baselines ranging from 8m to 200m.
- Collection of light with four 8 m Unit Telescopes (UTs) and four 1.8 m Auxiliary Telescopes (ATs).
- Wavefront correction at the telescopes: in the first phase adaptive optics for the UTs (MACAO) and tip-tilt correction for the ATs (STRAP).
- Transportation of the primary and secondary beams from the telescopes to the focal lab.
- Compensation by the delay lines (DLs) of the optical path difference due to the sidereal motion.
- Correction of the slow (<1 Hz) tip/tilt motion of the beams (caused by tunneling seeing effects) by means of a fast detector sensing the beam motions and sending corrections to the X-Y table so that the beams are kept centered on the optical axis (IRIS). IRIS uses 25% of the K-band for the guiding.
- External fringe tracking with FINITO. This is available on **both** the UTs and the ATs and allows AMBER to reach longer DITs as FINITO is freezing the fringes on the detector. The advantage is twofold, first, in MR and HR modes it is always possible to read out the full spectral range on the detector, secondly, the longer DITs allows going much fainter than with the short DITs used without fringe tracking. The magnitude limits are imposed by the FINITO fringe tracking limits. These are for most modes (MR and HR) fainter than the standalone limits but there are constraints in airmass and minimum visibility that are stricter than AMBER in standalone operation.

3.2 Other VLT instruments

AMBER yields information at scales between λ/B and λ/D. A single mode instrument like AMBER has therefore no direct access to structures larger then λ/D. Like for radio interferometer, one might need in certain cases information at small spatial frequencies in order to inject it with the data collected with AMBER. The best-suited instruments that can give access to these data are the NAOS/CONICA and SINFONI, which measure diffraction-limited images in the the same wavelength domain as AMBER. With NAOS/CONICA it is

Table 1: AMBER characteristics and observing capabilities

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
Visibility accuracy	9% (3σ)
Optical throughput	2% in K
	1% in J and H
Detector size	1024×1024 detector array
Detector read-out noise	11.37^{-}
Detector quantum efficiency	0.8
Observables	$V(f, \lambda)$,
	$V(f, \lambda)/V(f, \lambda_0)$,
	$\Phi(f, \lambda) - \Phi(f, \lambda_0)$,
	$\Phi_{123}(\lambda)$

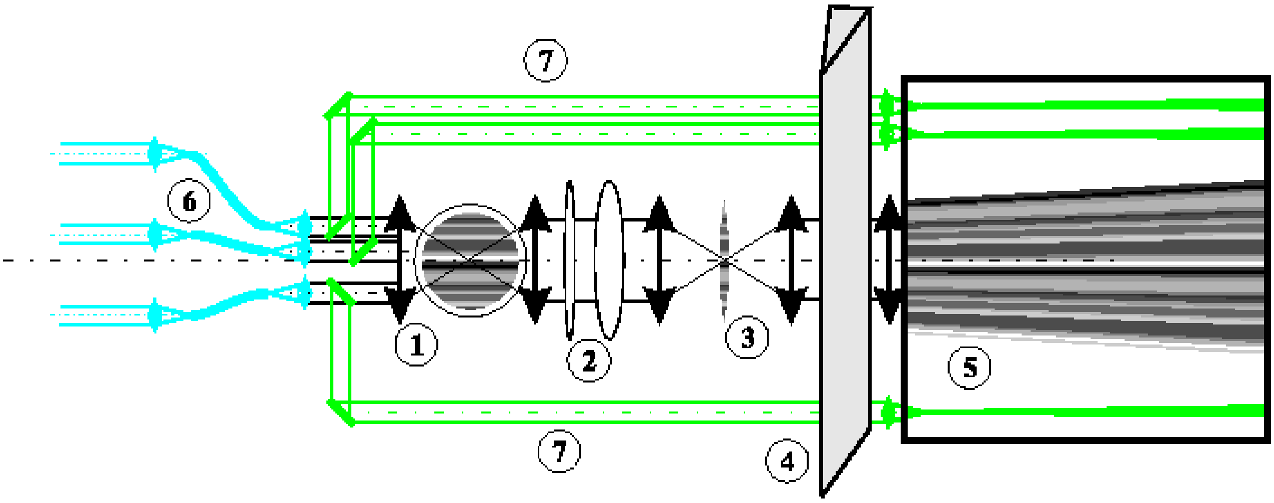

Figure 1: Basic concept of AMBER: (1) multi axial beam combiner. (2) cylindrical optics. (3) anamorphosed focal image with fringes. (4) "long slit spectrograph". (5) dispersed fringes on 2D detector. (6) spatial filter with single mode optical fibers. (7) photometric beams.

possible to do both imaging and spectrography and SINFONI is unique in that it does full field spectrography 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 similar to AMBER but 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`.

4 AMBER overview

4.1 AMBER principle

Figure 1 summarizes the key elements of the AMBER concept. AMBER has a multi axial beam combiner. 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 output baselines are in a non-redundant setup, i.e. the spacing between the beams is selected for the Fourier transform of the fringe pattern to show separated fringe peaks at all wavelengths. 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. To minimize detector noise each spectral channel is 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). For work in the K band with resolutions up to 12 000 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 we found it simpler to cool it down to liquid nitrogen temperature.

To produce high accuracy measurements, it is necessary to spatially filter the incoming beams to force each one of them to contain only a single coherent mode. To be efficient, the spatial filter must transmit at least 10^3 more light in the guided mode than in all the secondary modes. For the kind of imperfect AO correction (Strehl ratios often <50%) available for the VLTI, the single way to achieve such high filtering quality 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 before the beam combiner and sent directly to the detector through a dispersive element (-7- in Fig. 1). The instrument must also perform some beam "cleaning" before entering the spatial filter, such as correcting for the differential atmospheric refraction in the H and J bands or, in some cases, eliminating one polarization.

4.2 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

4.2.1 Warm optics

There are three spatial filters, one for each spectral band, because of the limited wavelength range over which a fiber can remain single mode. The three spatial filter inputs 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 to use the same spectrograph achromatic optics for all bands and to have the same sampling of all the central wavelengths.

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.

4.2.2 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.

4.2.3 Detector

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

4.2.4 Calibration unit

The Calibration and Alignment Unit (OPM-CAU), contains all calibration lamps and can emulate the VLTI in the integration, test and calibration phases. The matrix calibration

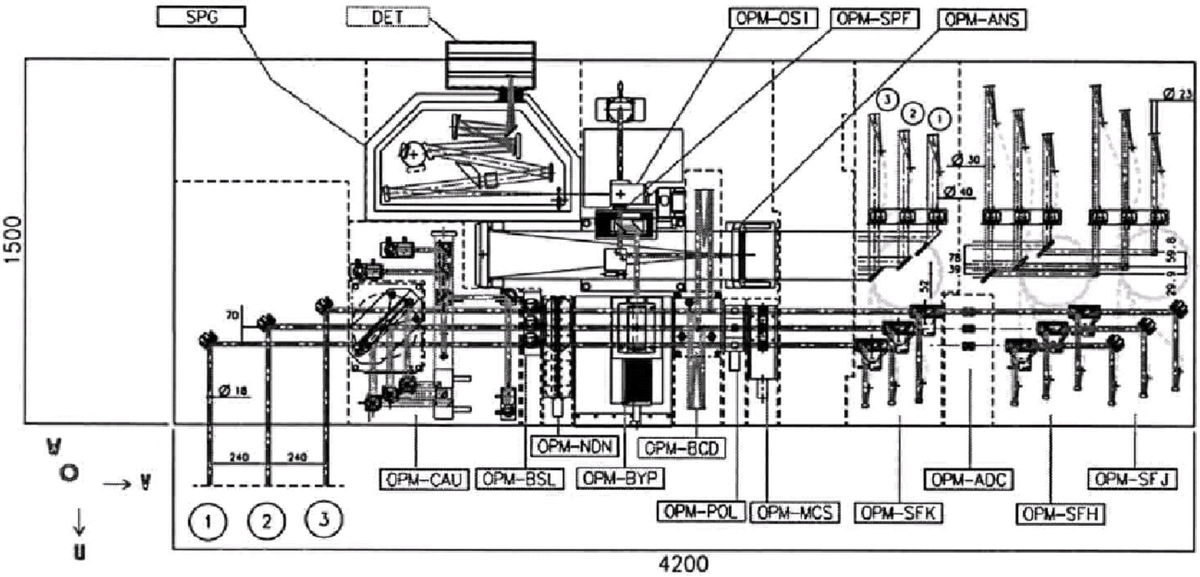

Figure 2: Amber global implementation

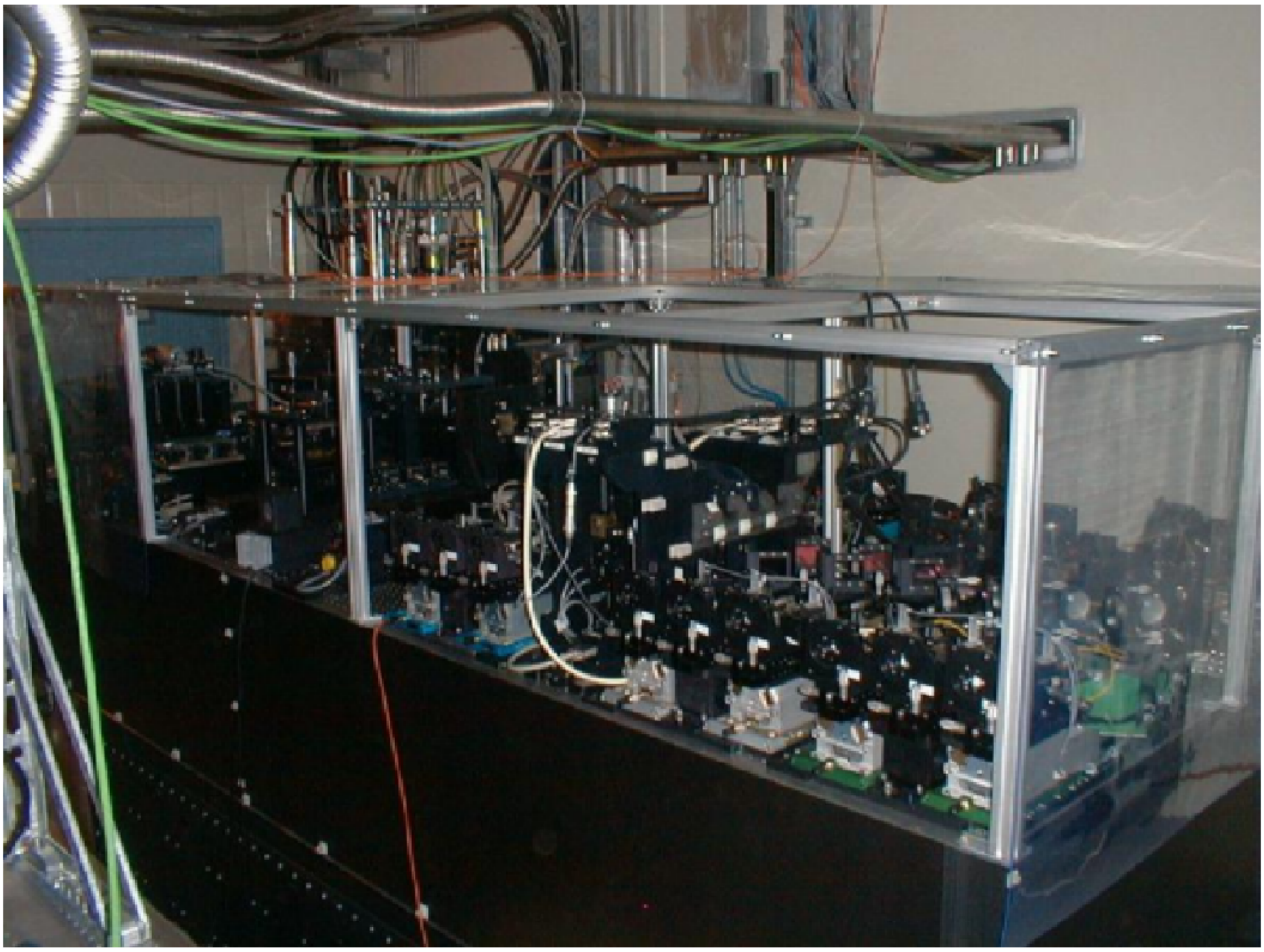

Figure 3: Photography of AMBER at Paranal

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 matrix of the "pixel to visibility" linear relation.

Several components of the AMBER instrument, such as the dichroics, the fibers, the filters, the beam splitter, the cryostat window are optimized for only one polarization. Then, the other polarization will provide only a small gain in flux but can produce a substantial loss in contrast. To avoid this, one polarization is eliminated by polarization filters (OPM-POL) located on the AMBER table before the dichroics.

4.3 From images to visibilities

The raw data produced by AMBER are images of the overlap of the 3 beams dispersed by a prism (LR) or grisms (MR and HR). Because of the beam splitter, 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. In fact, three fringe systems are present in the interferometric output, and, the first action consists in separating them apart. During the calibration, the carrying wave corresponding to each baseline is recorded and the interference term of the base ij is for the pixel k:

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

The quantities $c_{ij}(k)$ and $d_{ij}(k)$ are called the carrying waves and are displayed in Fig. 5. These waves are in quadrature so that each pixel is sensitive to a complex number. Therefore we can write the photometry subtracted interferogram $i_{\mathrm{corr}}(k)$ as:

$$i_{\mathrm{corr}}(k) = \sum_{j>i} m_{ij}(k) \tag{2}$$

$$= M(k) \times C \tag{3}$$

where C is a vector of the values $(R_{ij},\ I_{ij})$ corresponding respectively to the real- and imaginary-part of the correlated flux $2\sqrt{P_iP_j}\,V_{ij}$ 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). During calibration, one can measure the P2VM and then inverse it so that for each pixel we get the visibility.

4.4 Instrument performances

The user should read the AMBER webpages (`http://www.eso.org/instruments/amber/inst/`) for the latest information on the AMBER performance.

4.5 Instrumental contrast

The inherent instrumental contrast of AMBER is measured during the P2VM calibration procedure that occurs every time that we change the spectral set-up of the instrument after the fibers. The P2VM observation is automatically included in the standard templates and thus requires no input or configuration by the observer. Please, read section 4.3 for an extensive explanation of the use of the P2VM during data reduction.

5 Instrument features and problems to be aware of

The AMBER instrument is not yet fully commissioned. The following caveats 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.
- OPD model may not be completely optimized and time can be lost to find fringes in particular in the LR mode.
- On the ATs and UTs FINITO is available and thus in all modes 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.
- Differential visibilities and phases (see sections 2.1 and 2.2.3) can be used.
- AMBER is a single-mode instrument and therefore the field of view 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.

6 AMBER in P83

AMBER combines most of the aspects that usually exist independently in several astronomical instruments. It involves visibility measurements (interferometry), spectral dispersion (spectroscopy), and background level corrections. Hence, AMBER in its final configuration will feature a large number of modes selectable by the user. However, most of the modes are still under development.

In P83 the only modes offered will be the High Resolution K band (HR-K), Medium Resolution K band (MR-K) 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 and H-band is sent undiminished to AMBER. Note that if FINITO is used on the ATs then FINITO will use either 75% or 100% of the H band flux.

Note that starting in P83 , FINITO is now part of the standard mode in HR-K and MR-K. Any proposal asking not to use FINITO in these modes should properly explain the reason why and require a waiver.

See the AMBER instrument webpage:
`http://www.eso.org/instruments/amber/inst/`
for the most recent information on the exact wavelength ranges and section 7.2.1 for the configuration options for the spectrograph.

6.1 Service and Visitor Modes

For P83 , 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.

7 Preparing the observations

Submission of proposals for AMBER should be done through the ESOFORM. It is important to 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 and for which AMBER could reveal interesting features, the first thing to do is to determine whether this target can be observed with AMBER or not.

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' and that the proposal is marked as time critical (see the ESOFORM package for details).

At this point, AMBER is offered with conservative performance estimates. The details of the current magnitude limits can be found at the AMBER instrument webpage:
http://www.eso.org/instruments/amber/inst/

7.1 Choice of the VLTI configuration

7.1.1 Telescopes

The available telescopes for AMBER are the 8 m Unit Telescopes (UTs) and the 1.8 m Auxiliary Telescopes (ATs). For detailed information on the UTs, ATs, and their active optics subsystems please see Sections 7.1.3 and 7.1.4. What is important in the choice of telescopes is the needed light collecting area and the baseline between the telescopes, and not the maximal baseline across the mirror.

7.1.2 Baselines

For a list of the offered telescope configurations, please refer to the to the VLTI baseline page at http://www.eso.org/paranal/insnews/vlti/. This page contains detailed information about the baseline lengths, angles and available telescope triplets using the UTs or the ATs.

7.1.3 Coudé guiding with the UTs

Each UT is equipped with an adaptive optics system called MACAO. It consists of a Roddier wavefront curvature analyzer using an array of 60 avalanche photodiodes. This analyzer applies a shape correction on the M8 deformable mirror of the UT. The M8 is mounted on a tip-tilt correction stage. In this case, the telescope is tracking in "field stabilization" mode. In this mode, the Nasmyth guide probe camera tracks on a selected guide star (observable within the

30-arcmin Nasmyth FOV which is centered on the science target) by tip-tilting the M2. When at limit, the M2 is offloaded to the alt-az axes of the telescope. The tip-tilt mount of the M8 is offloaded by offsetting the Nasmyth guide probe position, and therefore by offsetting the M2 or the alt-az axes. The sensitivity of MACAO is V=16 for a 20% Strehl at 2.2μm (compared to the 50% Strehl at V<12, at which the AMBER limiting magnitudes were estimated). In practice with AMBER, MACAO can be used with V=17 with the limitations that reduced Strehl will yield.

Note: There is also the additional constraint that the object should be fainter than V=1 for MACAO to work properly. The user should also be aware that Coudé guiding is not guaranteed to work for objects with 15<V<17 and the user should preferably select another guide star.

If the target to observed is fainter than V=17, it is possible to perform "off-target Coudé guiding", provided a suitable guide star exists. This guide star must be brighter than V=17 and closer than 57.5 arcsec to the target to be observed with AMBER.

It should be clear that the fainter the Coudé guide star the less optimal correction on the science object ie. objects close the limiting magnitudes of AMBER should use bright (V_{mag}<13) guide stars and not request seeing worse than 0.8".

The effective correction done by MACAO drops with distance between the Coudé guide star and the science object and under nominal weather conditions the effective limiting magnitude drops by one magnitude for every 15" separation between the two stars.

There are also a few weather/external/observing condition constraints for proper MACAO performance:

- Seeing < 1.5 arcsec.
- τ_0 >1.5 ms.
- Airmass <2

These constraints do not affect Service observations as OBs are only classified as A or B if MACAO has been performing within the tolerances. The constraints are given here for Visitor mode observations to give the user the conditions under which MACAO will perform as expected. Thus during non ideal weather conditions outside the MACAO performance ranges the user could ameliorate the effects to some degree by only using brights guide stars and only observe at high elevation.

Note that the constraints for using FINITO+AMBER on the UTs are much stricter. The maximum distance is 15 arcsec and the Coudé guide star cannot be fainter than 13th magnitude in V.

7.1.4 Coudé guiding with the ATs

Each AT is equipped with the tip-tilt corrector called STRAP. It consists of a avalanche photodiode quadrant which measures the tip-tilt of the incoming wavefront. The measured tip-tilt is compensated by acting on the M6 mobile mirror. When at the limit, M6 is offloaded to the alt-az axes of the telescope. The sensitivity of STRAP on the ATs is V_{mag}=13. If the target to observed is fainter than V_{mag} ~13, it is possible to perform off target Coudé guiding, provided a suitable guide star exists. This guide star must be brighter than V_{mag} ~13 and closer than 57.5 arcsec to the target to be observed with AMBER. If V_{mag} is fainter than 12, there is a risk that Coudé guiding cannot be performed, depending on the off-axis distance and on the sky conditions (seeing, τ_0). It should also be noted that the expected correction with STRAP drops with distance between the science target and the Coudé guide star. Having a Coudé off-axis guide star at the formal maximum off-axis distance will not allow AMBER to reach the specified limiting magnitudes. Thus it is strongly recommended that the Coudé guide star is brighter than V_{mag} ~12 and as close as possible to the science target.

For proper AMBER+FINITO operation on the ATs the constraints for STRAP are much stricter and the maximum distance is 15 arcsec and the Coudé guide star is brighter than V_{mag} ~11.

7.1.5 Geometry

Important parameters of the instrument to be taken into account for the preparation of the observing schedule are the VLTI geometry during observation ((u, v) coverage). The selection of the baseline requires the knowledge of both the geometry of the VLTI and of that of the target. To assess observability of a target with VLTI, it is suggested to use the VisCalc software, as this is the only ESO supported software. The front-end of VisCalc is a comprehensive web-based interface. VisCalc can be used from any browser from the URL:
`http://www.eso.org/observing/etc.` Since we had problems in service mode in the past with over-resolved targets (which appeared resolved in imaging mode at the acquisition, or for which no fringes were found), we encourage the user to collect as much information on their target as possible, before submitting an AMBER proposal.

7.1.6 Guaranteed time observation objects

It is important to check any scientific target against the list of guaranteed time observation (GTO) objects. This guaranteed time period covers the full P83 . To make sure that a target has not been reserved already, the list of GTO objects can be downloaded from:
`http://www.eso.org/observing/proposals/gto/amber/index.html`

7.1.7 Calibrator Stars

High quality measurements require that the observer minimizes and calibrates the instrumental losses of visibility. To get a correct calibration, the user should use appropriate calibrator stars in terms of target proximity, calibrator magnitude and apparent diameter. In the case of AMBER, the calibrator is observed after the science target, using the same templates. For each science target, a calibrator star must 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. CalVin can be used from any web browser. Like `VisCalc`, `CalVin` can be used on the web from:
`http://www.eso.org/observing/etc/`

7.1.8 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 come into effect but can be limiting to observations of objects that consists of several components *e.g* binaries, stars with disk and/or winds, etc.

The observer should be aware that if the components are separated by more than the FoV, only one of the components will be seen by AMBER.

7.1.9 Complex fields

For normal observations of single objects there are no special constraints on the seeing, it is sufficient that MACAO or STRAP are working within the normal constraints (see Sections 7.1.3 and 7.1.4). When observing complex fields with several objects within a few arcseconds the situation is more complex. 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. Due to the way that light is injected into AMBER (injection procedure only maximizes the flux injected into the fiber) it cannot be guaranteed in the case of separations smaller than ∼0.3 arcsec that the proper target has been injected into the fiber. These kinds of observations will have to follow a non-standard extensive procedure to perform the injection adjustment and will require the presence of the PI (Visitor Mode).

7.1.10 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.

7.2 Choice of the AMBER configuration

7.2.1 Instrument set-up

The instrument set-up is defined by the spectral configuration of the instrument and the 3T configuration. In each 3T configuration the spectral configuration can be:

- $\mathcal{R} = 35$: 75% K band and 100% H band with IRIS guiding (`Low_HK`).
- $\mathcal{R} = 1500$: 75% K band in medium resolution with IRIS guiding (`Medium_K_1_2.1` and `Medium_K_1_2.3`).
- $\mathcal{R} = 12000$: 75% K band in high resolution with IRIS guiding (`High_K_X.XX`).

On the ATs with or without FINITO the following modes are available:

- $\mathcal{R} = 35$: 75% K band and 25% H band with IRIS guiding and FINITO fringe tracking (`Low_HK`), if FINITO is not used then 100% of the H band is sent to AMBER.
- $\mathcal{R} = 1500$: 75% K band with IRIS guiding and FINITO fringe tracking in medium resolution (`Medium_K_1_2.1` and `Medium_K_1_2.3`).
- $\mathcal{R} = 12000$: High resolution K-band observations with FINITO as an external fringe tracker, where 25% of K band is used by IRIS.

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).

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 polarizes, 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.

7.2.2 Observing modes

The situation is now more complex as FINITO the external fringe tracker is now available on both the UTs and the ATs. Without FINITO either on the UTs or on the ATs the **observing mode** is characterized by the detector integration time (DIT). Currently only fixed DITs of 25, 50, or 100 ms (ATs only) are offered using the UTs and ATs. With FINITO longer DITs are available allowing in all spectral modes to read out the full spectral range. The user should consult with the AMBER Instrumentation webpages for further information on the available integration times.

7.2.3 Calibration cycle

7.2.4 Calibrating the background emission

It is necessary to measure the sky and the instrumental emission in order to subtract this background to the science images. The procedure consists in observing a source free region. This observation is performed with the same set-up as the science observation and close in time (about 5 minutes) and is included in the estimated time for the science observation.

7.2.5 Standard calibration the instrumental visibility (`Std`)

It is necessary to determine the instrumental complex visibility that affects (multiplicatively) the measured visibility. The procedure consists in observing a point-like source, or a target which intrinsic visibility is known (the reference object has to be close to the science object). This observation has to be performed with the same set-up as the science observation and close in time.

The standard calibration plan for service mode observations includes a pair of one science OB and one calibrator OB (sci-cal). Sequences of cal-sci-cal can be requested as a special calibration requirement. The requested time should be corrected accordingly.

8 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), a series of OBs must be constructed. An OB can contain only one target, but can contain several telescope offsets to measure the sky for example.

In the case of interferometry instruments, the situation is a little bit different since we need calibrator stars to assess the atmosphere + instrument system visibility (cf. Sect. 7.2.3). 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.

8.1 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.

8.1.1 Observing cycle

A standard observation with AMBER in P83 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. 4.2.4.
3. Acquisition: Slew telescopes to target position on sky, and slew the delay-lines to the expected zero-OPD position and bring the DLs in "tracking" state (pre-defined sidereal trajectory).
   (a) As stated in Secs 7.1.3 and 7.1.4, the user has the possibility to use a guide star for the Coude systems, different from the target. He/she will have to indicate the coordinates of this star, which, for the UTs should be brighter than V=17 and fainter than V=1 and within a 1-arcmin radius from the science target. On the ATs the limits are stricter where the object has to be brighter than V=13.
4. Injection Adjustment: Adjust telescope positions, so the beams from the target will center on the injection fibers in AMBER.
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 P83 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 or HR-K observations.
8. If FINITO is used longer DITs are available.

8.2 Computing time overheads for added bands

The user should assume that 70 minutes are required for one calibrated visibility point (ie, a measurement of the science object and a measurement of an interferometric calibrator star). This applies to LR-HK, and to Medium Resolution Observations (MR) or High Resolution Modes (HR) for one spectral setting. Users interested in obtaining visibility measurements at several spectral positions inside the K band should add 30 minutes for each additional spectral band. Similarly if the user is interested to repeat the same spectral band to obtain more frames with sufficient SNR then the user should add 30 minutes for each repeated spectral band. A maximum of 3 bands per observation (*i.e.* per OB) is allowed. Users interested in obtaining an additional calibrator observation (cal-sci-cal sequence) should add 35 minutes per sequence.

9 Bibliography

- *Observing with the VLT Interferometer* Les Houches Eurowinter School, Feb. 3-8, 2002; Editors: Guy Perrin and Fabien Malbet; EAS publication Series, vol 6 (2003); EDP Sciences - Paris.
- *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)

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
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
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

–oOo–

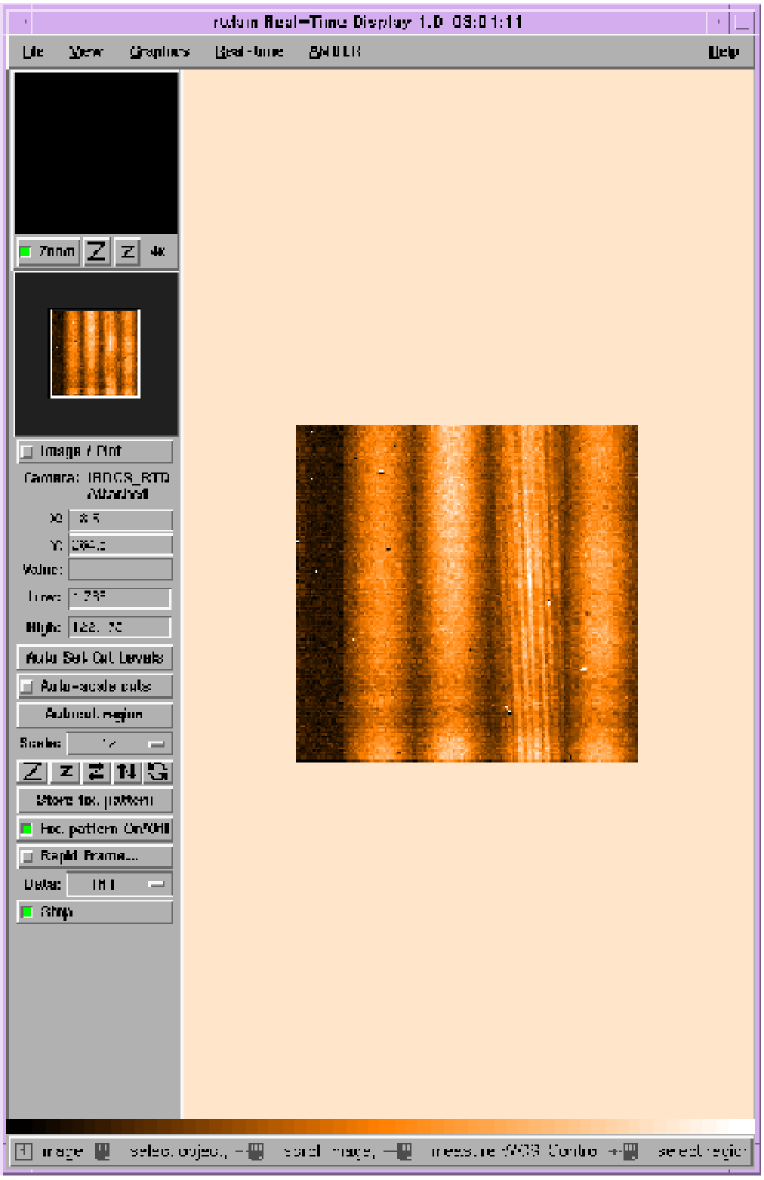

Figure 4: Image of the fringes recorded by AMBER in medium resolution around 2.1 microns using an artificial light-source. The wide stripes are the photometric spectrum of the 3 beams and the band with narrow stripes is the interferometric channel with the fringes.

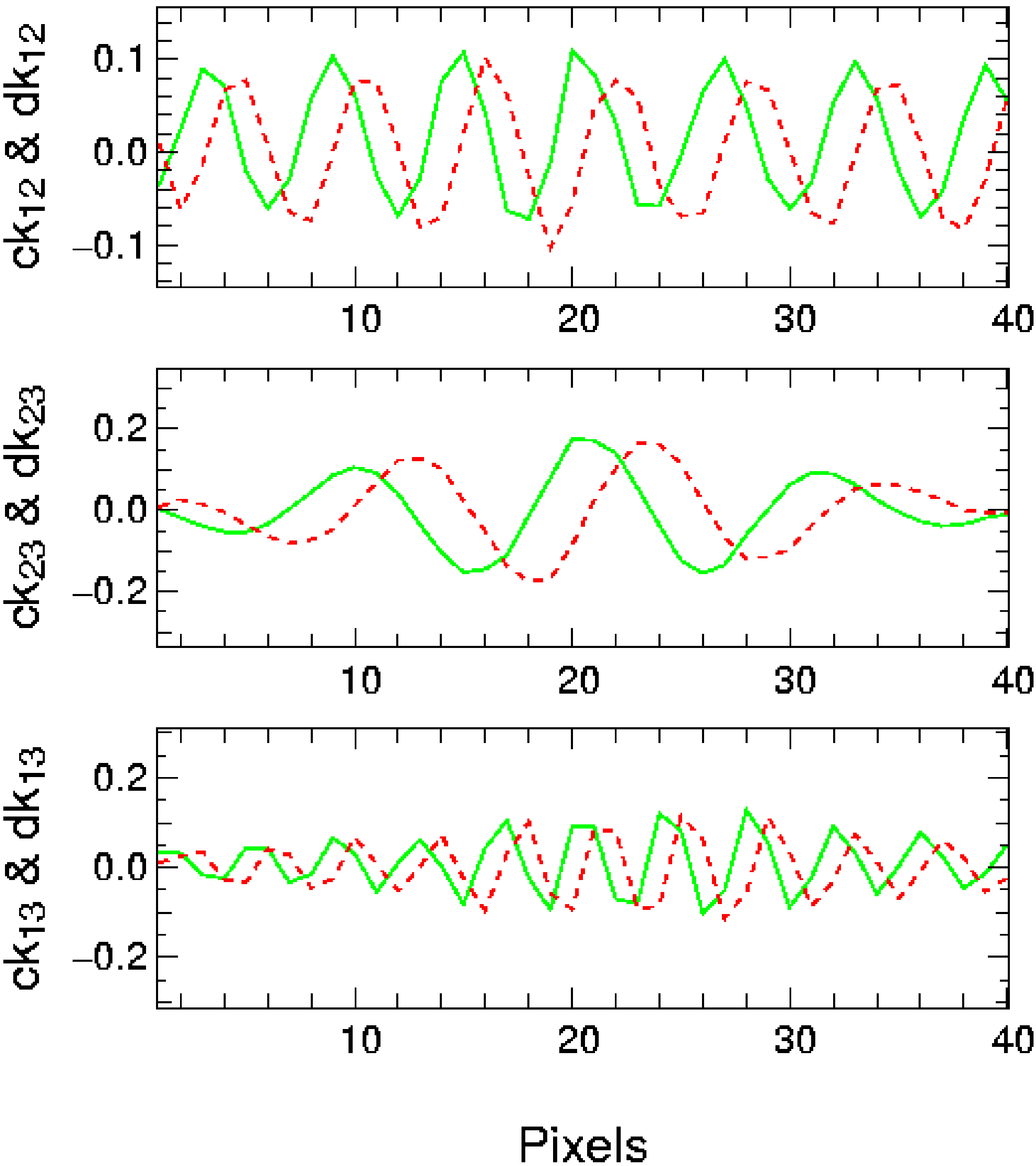

Figure 5: Example of carrying wave $c(k)$ (solid green line) and $d(k)$ (dashed red line).

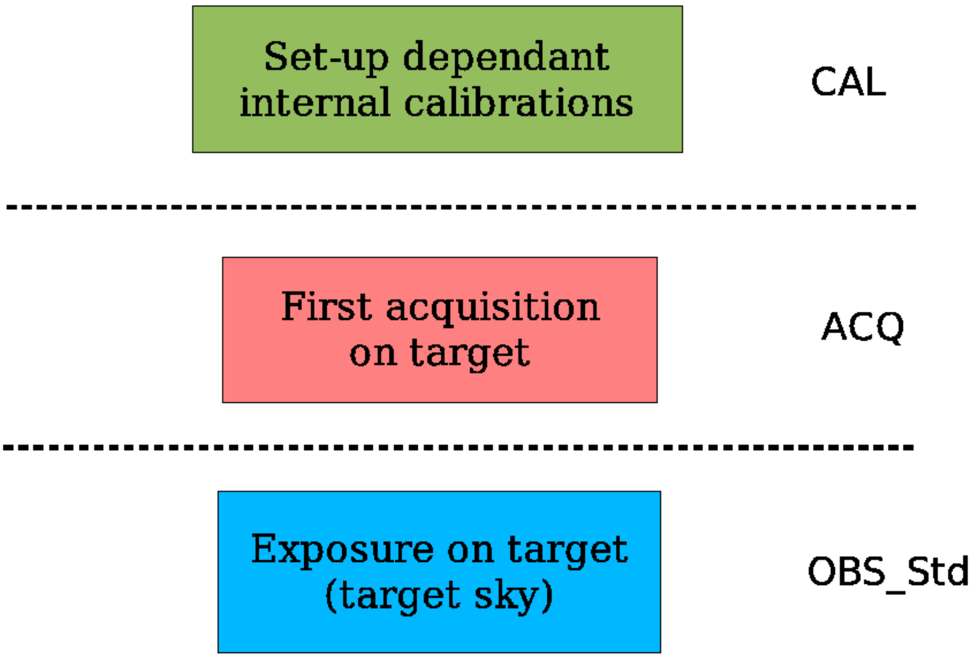

Figure 6: Standard observation mode (`Std`).