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Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral

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## VERY LARGE TELESCOPE

### AMBER Pipeline User Manual

VLT-MAN-ESO-19500-4221

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# 1 Introduction

## 1.1 Purpose

The AMBER pipeline is a subsystem of the *VLT Data Flow System* (DFS). Its target user is ESO *Data Flow Operations* (DFO) in the generation of master calibration data, in the reduction of scientific exposures and in the data quality control. It should also serve as a quick look tool for *Paranal Science Operations* (PSO). Additionally, the AMBER pipeline recipes are made public to the user community, to allow a more personalized processing of the data from the instrument.

This manual is a complete description of the data reduction recipes used by the the AMBER pipeline, reflecting the status of the AMBER pipeline as of May 2007 (version 2.3.7).

## 1.2 Acknowledgments

The software package on which the AMBER pipeline is based on was in large parts developed by the AMBER Consortium, and it is still the foundation of the current AMBER interferometry data reduction.

## 1.3 Scope

This document describes the AMBER pipeline used at ESO-Garching and ESO-Paranal for the generation of master calibration data and data quality control.

## 1.4 Reference and applicable documents

- |      |   |                            |
|------|---|----------------------------|
| [1]  | AMBER Data Reduction Plan                                 | VLT-PLA-AMB-15830-6004     |
| [2]  | VLT Data Flow System Specifications for Pipeline and QC   | VLT-SPE-ESO-19600-1233     |
| [3]  | Data Flow for VLT instruments Requirement Specification   | VLT-SPE-ESO-19000-1618/2.0 |
| [4]  | DFS Pipeline & Quality Control – User Manual              | VLT-MAN-ESO-19500-1619     |
| [5]  | ESO DICB – Data Interface Control Document                | GEN-SPE-ESO-00000-0794     |
| [6]  | Common Pipeline Library User Manual                       | VLT-MAN-ESO-19500-2720     |
| [7]  | Gasgano User's Manual                                     | VLT-PRO-ESO-19000-1932     |
| [8]  | AMBER Calibration Plan                                    | VLT-PLA-AMB-15830-0004     |
| [9]  | AMBER product data specification                          | VLT-SPE-AMB-15830-3984     |
| [10] | AMBER data reduction software design description document | VLT-TRE-AMB-15830-4107     |

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## 1.5 Abbreviations and acronyms

ADF	Aperture Definition File
ADM	Aperture Definition in mm
AMBER	Astronomical Multi BEam combineR
AT	Auxilliary Telescope
CPL	Common Pipeline Library
CRV	Spectral curvature model
DFS	Data Flow System
DMD	Data Management Division
DO	Data Organiser
DRS	Data Reduction System
ESO–MIDAS	ESO's Munich Image Data Analysis System
FITS	Flexible Image Transport System
HR	High Resolution
ICS	Instrument Control Software
IDS	Inverse Dispersion Solution
IRAF	Image Reduction and Analysis Facility
IWS	Instrument WorkStation
LR	Low Resolution
MMU	Mask Manufacturing Unit
MOS	Multi Object Spectroscopy
MR	Medium Resolution
P2VM	Pixel To Visibility Matrix
PAF	VLT PArAmeter File
PWS	Pipeline WorkStation
QC	Quality Control
RB	Reduction Block
RBS	Reduction Block Scheduler
SAO	Smithsonian Astrophysical Observatory
SNR	Signal to Noise Ratio
SOF	Set Of Frames
TCS	Telescope Control Software
UT	Unit Telescope
VLT	Very Large Telescope
VLI	Very Large Telescope Interferometer
WCS	World Coordinate System

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## 2 Overview

The AMBER pipeline is a collection of data reduction recipes administrated by the higher level programs of the *VLT Data Flow System* (DFS) [2].

The *VLT Data Flow System* provides an environment where the definition and the execution of the data reduction steps can be made entirely automatic. The fundamental DFS software components making up the required functionality are the *Data Organizer* (DO) and the *Reduction Block Scheduler* (RBS). The DO applies some defined instrument-dependent rules for the classification of the incoming frames, for their association to suitable calibration data, and for launching the appropriate recipe for their standard reduction. The product of the DO is the *Reduction Block* (RB), an ASCII file containing all the necessary information for the specific data reduction. The RB is executed by the RBS, which calls the assigned pipeline recipe with the appropriate parameters and makes the data reduction products available to the *Data Handling Server* (DHS).

The AMBER pipeline recipes can also be used outside the pipeline context, as stand-alone programs. In this way they may be easily used by astronomers at their home institutes, or taken as building blocks for different data reduction strategies. However, the pipeline recipes, being designed to operate within the DFS environment, do not repeat the checks already performed by the DO. In other words, data classification and appropriate association are not re-verified within a recipe. The *Gasgano* ([7]) data browser, capable of classifying the data frames in the same way as the DO, greatly assists in the administration of the different data frames.

The AMBER instrument and the different types of AMBER raw frames are briefly described in Sections 3 and 4, while the usage of the available reduction recipes is presented in Section 5.

In Appendix A the installation of the AMBER pipeline recipes is described, whereas a more detailed descriptions of the data reduction algorithms used by the individual pipeline recipes can be found in Appendix B.

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### 3 AMBER Instrument Description

AMBER has been developed under ESO contract by the AMBER Consortium, headed by the Laboratoire d'Astrophysique de Grenoble with contributions from Observatoire de la Côte d'Azur, Laboratoire Universitaire d'Astrophysique de Nice, MPI für Radioastronomie - Bonn and Osservatorio Astrofisico di Arcetri.

The instrument has been made available to the community and started Service Mode Operations in Paranal on October 1<sup>st</sup>, 2005.

In this chapter a brief description of the AMBER instrument is given. A more complete documentation can be found in the AMBER User Manual, which can be retrieved from:

<http://www.eso.org/instruments/amber/>

#### 3.1 Overview

AMBER is the first-generation near-infrared three-way beam combiner. This instrument (see Figure 3.1.1) provides simultaneously spectrally dispersed visibility for three baselines and a closure phase at three different spectral resolutions. AMBER has been designed to investigate the milli-arcsec surrounding of astrophysical sources like young and evolved stars, active galactic nuclei and to detect exoplanets.

The main new feature of AMBER if compared to other interferometric instruments is the simultaneous use of modal filters (optical fibers) and a dispersed fringe combiner using a spatial coding (see Figure 3.1.2). The AMBER team has therefore carefully investigated a data processing strategy for this instrument and is providing a new type of data reduction method.

#### 3.2 Observation Modes

AMBER offers three different modes of resolutions and three different bands in the following combinations:

Resolution Mode	Abbreviation	Description
Low Resolution	JHK-LR	The J, H and K bands are covered simultaneously
Medium Resolution	JH-MR	The J and H bands are covered simultaneously
Medium Resolution	HK-MR	The H and K bands are covered simultaneously
High Resolution	J-HR	The J band is covered
High Resolution	H-HR	The H band is covered
High Resolution	K-HR	The K band is covered

Please note that the spectral coverage of the high spectral resolution does not cover the entire bands.

Depending on the type of science required, one can choose to observe with AMBER in a classical way or in differential mode. The differential mode involves slight differences in the observing procedures but allows to obtain higher precision on the differential phase. The expected accuracy are typically 1% for the high sensitivity mode, 0.1% for the high precision mode, and 0.01% for the phase in the high precision mode in the differential configuration. This can be used either to obtain angular information on very unresolved objects or to aim at very high accuracy like in the extrasolar planets programs.

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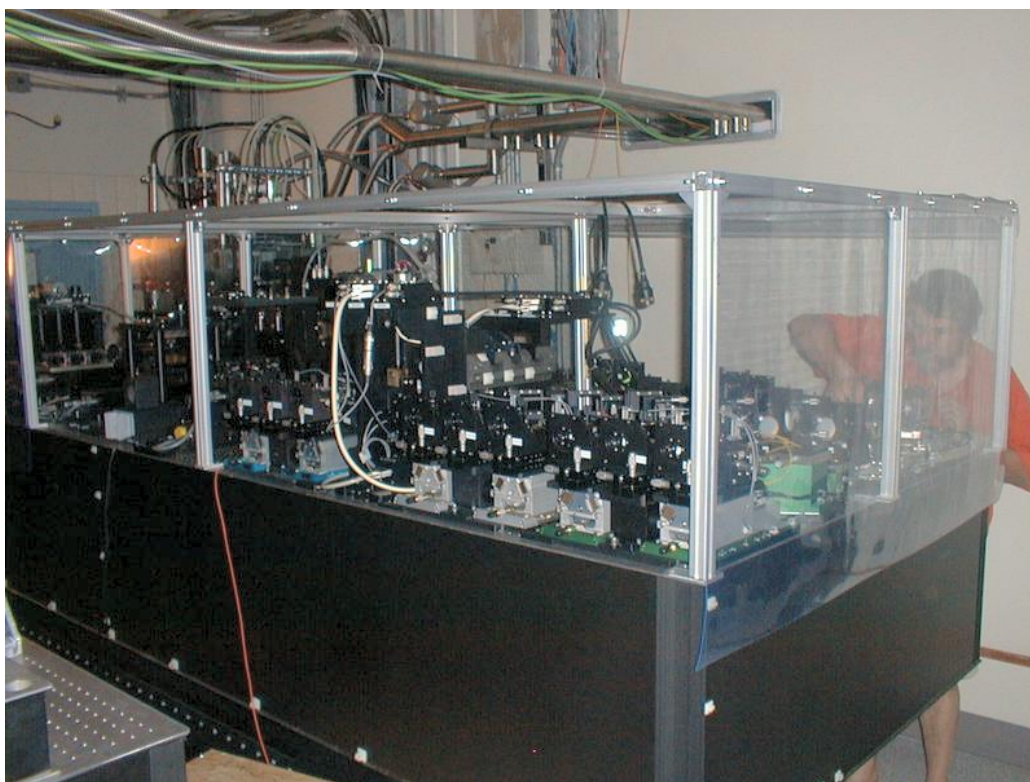


Figure 3.1.1: *The complex instrument AMBER consists of various optical and mechanical components to allow interferometric and spectroscopic observations at the same time.*

### 3.3 Angular Resolution

The angular resolution is set by the maximum available baseline, which is about 200 meters for the ATs and about 130 meters for the UTs. Accordingly, the limit will be about 2 milliarcseconds (mas) for the ATs and about 3 mas for the UTs in the K band. These values must be roughly halved for the J-band. Of course, the actual resolution will depend also on the signal-to-noise ratio (SNR), which is in turn a function of the source brightness, as well as many other factors (see below). Under conditions of a very high SNR, it is in principle possible to obtain even higher resolutions. This applies in particular to cases in which a source model is available and determinations of the visibility before the first zero are sufficient to constraint the size of the object (for instance, angular diameters and binary stars). Reversely, conditions of low SNR (for instance, for very faint sources), will limit the actual maximum resolution to values which can be substantially lower than the limits mentioned above. Another example is differential interferometry. If the source is not resolved, i.e. substantially smaller than the  $\lambda/B$  limit, then the differential phase still yields the displacement of the source photocenter as a function of wavelength, which in many cases has been shown to be able to provide decisive spatial information. The accuracy on the photocenter displacement is typically the  $\lambda/B$  resolution divided by the fringe SNR. For example in the case of AGN BLRs (proposal 4) it has been shown that in 20 minutes of actual observations on a  $K = 12$  object (with tracked fringes) one can achieve a 10 mas accuracy on the photocenter displacement.

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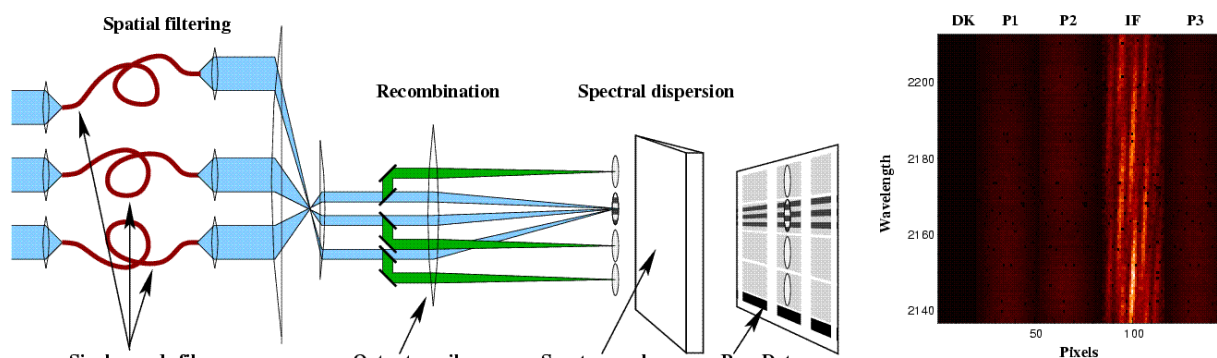


Figure 3.1.2: *Left panel: Sketch of the AMBER instrument. The light enters the instrument from left. Right panel: Reconstituted image from AMBER raw data in three-telescopes mode. DK corresponds to a dark region of the detector. Pk are vertically dispersed spectra from each telescope and IF is the spectrally dispersed interferogram.*

### 3.4 Flux Sensitivity

The limits in sensitivity depend on a large number of factors: observing modes that correspond to the elementary exposure time (high sensitivity: 50ms; high precision: 10ms; long exposures: any but with fringe tracking), the type of telescopes, the spectral resolution, the seeing, etc. Some of these are relatively well known and identified by the design of AMBER (e.g. transmission efficiency, fiber coupling, detector characteristics), while many others are more difficult to characterize at this time (e.g. the quality of fringe tracking and the adaptive optics correction).

### 3.5 Field Of View

AMBER is a single-mode instrument, therefore the field of view is theoretically limited to the Airy disk of each individual aperture, i.e. 250 mas for the ATs and 60 mas for the UTs in the K band.



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## 4 Instrument Data Description

AMBER data can be separated into *raw* frames and *product* frames. Raw frames are the unprocessed output of the AMBER instrument observations, while product frames are either the result of the AMBER pipeline processing (e.g. reduced frames, master calibration frames, etc.), or are the result of the calculation of the Pixel-To-Visibility-Matrix (P2VM).

Any raw or product frame can be classified on the basis of a set of header keywords. Data classification is typically carried out by the DO or by *Gasgano* [7], that applies the same set of classification rules. The association of a raw frame with calibration data (e.g., of a science frame with a master flat field frame) can be obtained by matching the values of a different set of header keywords.

Each kind of raw frame is typically associated to a single AMBER pipeline recipe, *i.e.*, the recipe assigned to the reduction of that specific frame type. In the pipeline environment this recipe would be launched automatically.

A product frame may be input to more than one AMBER pipeline recipe, but it may be created by just one pipeline recipe (with the same exceptions mentioned before). In the automatic pipeline environment a product data frame alone wouldn't trigger the launch of any recipe.

In the following Section all raw and product AMBER data frames are listed, together with the keywords used for their classification and association. The indicated *DO category* is a label assigned to any data type after it has been classified, which is then used to identify the frames listed in the *Set of Frames* (see Section 5.3, page 20).

Please note that the actual rules used to classify the AMBER raw frames do contain more types of raw frames than listed below. This is for backwards compatibility with old AMBER data. Please refer to the AMBER.rul file (GASGANO) or the file `amber.bdd/amber.oca` (online pipeline) for more details.

Raw frames can be distinguished in *calibration* frames and *science* frames. Their intended use is implicitly defined by the assigned recipe.

### 4.1 Calibration Frames

These frames are used for instrument calibration.

- **Pixel To Visibility Matrix and Spectral Calibration:** These frames are for calculation of a Pixel-To-Visibility-Matrix. Optionally the 2WAVE and 3WAVE files can be send to the recipe. In that case the the recipe will also perform a new spectral calibration.

- DO category: AMBER\_2P2V  
Processed by: `amber_p2vm`

Classification keywords:  
DPR CATG = CALIB  
DPR TYPE = 2P2V  
DPR TECH =

Association keywords: Note:

DET NTEL

Number of Telescopes used

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– DO category: AMBER\_2WAVE

Processed by: amber\_p2vm

Classification keywords:

DPR CATG = CALIB

DPR TYPE = WAVE, 2TEL

DPR TECH =

Association keywords: Note:

DET NTEL

Number of Telescopes used

– DO category: AMBER\_3P2V

Processed by: amber\_p2vm

Classification keywords:

DPR CATG = CALIB

DPR TYPE = 3P2V

DPR TECH =

Association keywords: Note:

DET NTEL

Number of Telescopes used

– DO category: AMBER\_3WAVE

Processed by: amber\_p2vm

Classification keywords:

DPR CATG = CALIB

DPR TYPE = WAVE, 3TEL

DPR TECH =

Association keywords: Note:

DET NTEL

Number of Telescopes used

- **Badpixel Map and Flat Field Map raw files:** These frames are for calculation of a Bad Pixel Map and the Flat Field Map with the AMBER recipe.

– DO category: AMBER\_DETECTOR\_DARK

Processed by: amber\_detector

Classification keywords:

DPR CATG = CALIB

DPR TYPE = DARK

DPR TECH = IMAGE

Association keywords: Note:

DET NTEL

Number of Telescopes used

– DO category: AMBER\_DETECTOR\_FFM

Processed by: amber\_detector

Classification keywords:

DPR CATG = CALIB

DPR TYPE = FLAT, LAMP

DPR TECH =

Association keywords: Note:

DET NTEL

Number of Telescopes used



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- **Beam Position Monitoring:** These frames are for calculation of the Quality Control parameters to monitor the beam position of AMBER in the various optical configurations.

- DO category: AMBER\_BEAMPOS  
Processed by: amber\_BeamPos

Classification keywords:

DPR CATG = CALIB

DPR TYPE = STD

DPR TECH = IMAGE

Association keywords: Note:

DET NTEL

Number of Telescopes used

## 4.2 Scientific Frames

- **Scientific Observation:** These frames are for scientific observations. For the calculation of visibilities there is at least one science object frame needed. In addition there must be a valid P2VM as well as a Flat-Field and a Bad-Pixel-Map. For improved SNR it is useful to input the optional frames for sky and dark detector illumination.

- DO category: AMBER\_SCIENCE  
Processed by: amber\_SciCal

Classification keywords:

DPR CATG = SCIENCE

DPR TYPE = OBJECT

DPR TECH =

Association keywords: Note:

DET NTEL

Number of Telescopes used

- DO category: AMBER\_DARK  
Processed by: amber\_SciCal

Classification keywords:

DPR CATG =

DPR TYPE = DARK

DPR TECH = INTERFEROMETRY

Association keywords: Note:

DET NTEL

Number of Telescopes used

- DO category: AMBER\_SKY  
Processed by: amber\_SciCal

Classification keywords:

DPR CATG =

DPR TYPE = SKY

DPR TECH =

Association keywords: Note:

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Number of Telescopes used

- DO category: AMBER\_CALIB  
Processed by: amber\_SciCal

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Classification keywords:

DPR CATG = CALIB

DPR TYPE = OBJECT

DPR TECH =

Association keywords: Note:

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– DO category: AMBER\_P2VM  
Processed by: amber\_SciCal

Classification keywords:

DPR CATG = CALIB

DPR TYPE = P2VM

DPR TECH =

Association keywords: Note:

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## 5 Data Reduction

In this section the usage of the AMBER pipeline recipes is described. In particular, typical data reduction sessions for each instrument operating mode are presented in Sections 5.2 and 5.6.

### 5.1 Reduction Cascade

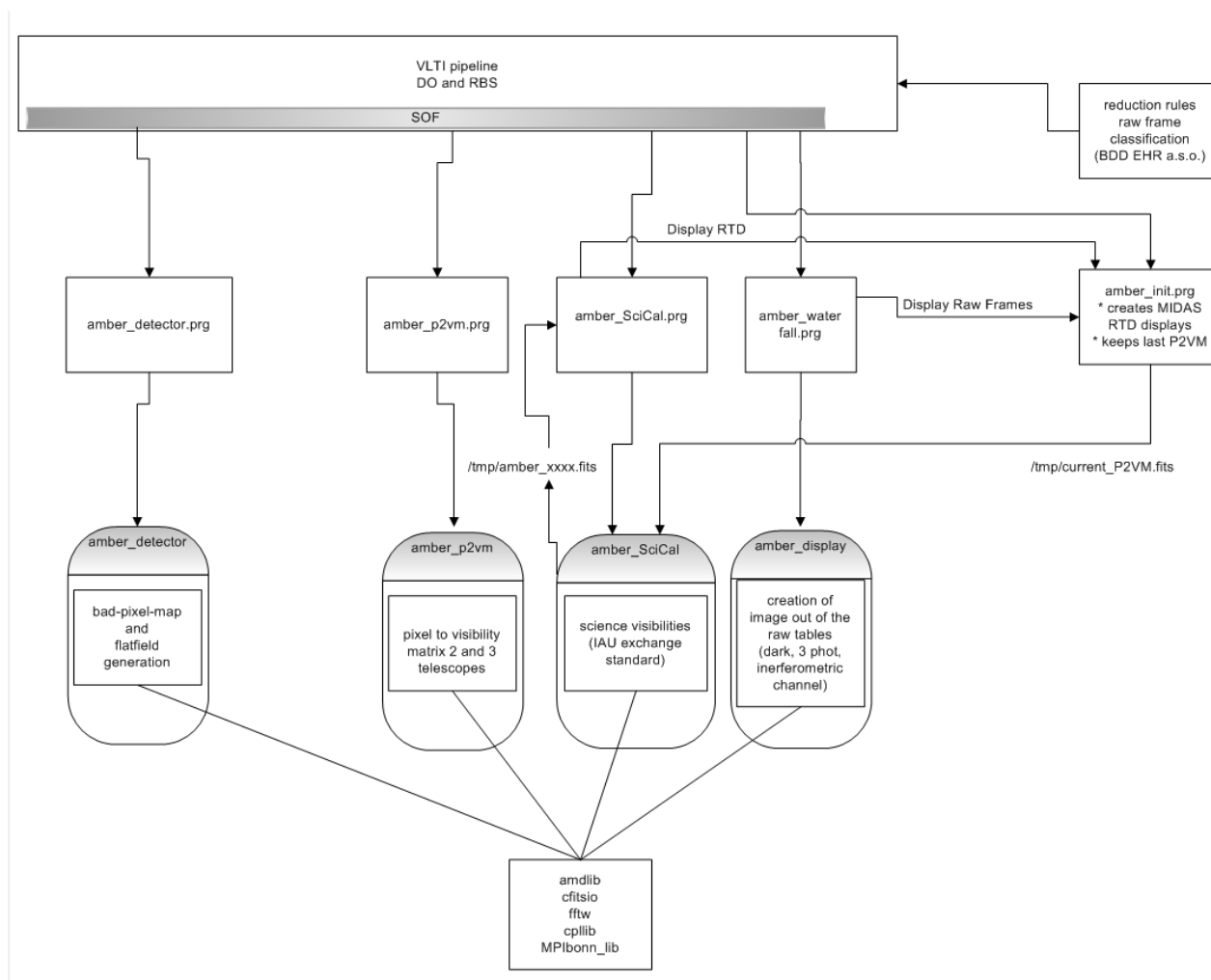


Figure 5.1.1: *AMBER Association Map*

### 5.2 AMBER pipeline recipes

The current AMBER pipeline is based on a set of stand-alone recipes, assigned to different fundamental operations. For the creation of general calibration data or informational output the following recipes can be used:

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- **amber\_raw\_to\_fitsimage:** As the AMBER raw frames are only containing number-tables, one can use this recipe to re-create a fits image out of this tables.
- **amber\_detector:** This recipe creates the master flat field and the bad pixel map for the optical train and detector of the instrument.
- **amber\_p2vm:** Calculation of the Pixel-To-Visibility-Matrix to be able to disentangle the interferometric channels for 2 and 3 telescopes. Optionally, if the specific raw frames are provided, it will also perform a spectral calibration. Moreover the recipe is also used to monitor the internal visibility of the instrument.
- **amber\_SciCal:** This recipe calculates the visibilities along with additional information like the SNR, error bars and the closure phase for the given band.
- **amber\_selector:** This recipe can select or filter the visibilities by various algorithm such as Fringe Contrast SNR
- **amber\_BeamPos:** This recipe is calculating the QC parameters for alignment monitoring of the optical train

In the following sections a general description on the usage as well as a more detailed information on the individual recipes is given. Moreover, there will also be a description of how to use the recipes with EsoRex and GASGANO.

### 5.3 The set of frames (SOF)

Each pipeline recipe processes a set of input FITS data files. The filenames are listed together with their DO category in an ASCII file, the *Set of Frames* (SOF; required when launching a recipe). SOF files containing the frames selected by the user are automatically created by *Gasgano* [7].

Here is an example of a SOF, valid for the *amber\_SciCal* recipe:

FlatFieldMap.fits	AMBER_FLATFIELD
BadPixelMap.fits	AMBER_BADPIX
AMBER.2006-02-11T05:13:36.596.fits	AMBER_P2VM
AMBER.2006-02-11T05:53:03.559.fits	AMBER_SCIENCE
AMBER.2006-02-11T05:55:15.715.fits	AMBER_SKY

The pipeline recipe will access the listed files when required by the reduction algorithm.

Please note that the AMBER pipeline recipes do not check the classification tags specified in the SOF. However, the recipe will check for every frame if the optical train is the same as it has been during recording the P2VM files. It will also check if all the regions in the files are consistent, since otherwise the usage of a particular P2VM file will result in incorrect data.

The reason for this lack of control is that the AMBER recipes are just the DRS component of the complete pipeline running on Paranal, where the task of data classification and association is carried out by the Data Organizer. On the other hand, using *Gasgano* [7] as an interface to the pipeline recipes will permit to classify the data frames exactly as the DO does.

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Please note that a recipe processing an incorrect SOF may stop with an error messages at best. In the worst cases, the recipe would run without any problem, producing results that may look reasonable while they are instead flawed.

## 5.4 Recipe configuration

At each pipeline recipe a configuration file, containing the default values of the parameters related to that recipe can be assigned. The possibility to create recipe configuration files, and the way information is conventionally stored in such files, depends on the front-end application used for launching the pipeline recipes<sup>1</sup>. In this section the recipe configuration files created and handled by *EsoRex* are described. Please refer to the Gasgano User's Manual [7] for information about saving recipe configuration parameters.

An *EsoRex* recipe configuration file can be generated in the directory `$HOME/.esorex` by *EsoRex* (see Section 5.5 on page 21) at installation time, and has the same name as the related recipe, with the filename extension `.rc`. For instance, the recipe *amber\_SciCal* has its *EsoRex* generated configuration file named `amber_SciCal.rc`. Please note that without a recipe configuration file the recipe will use the default values.

The definition of one parameter of a recipe may look like this:

```
# --Binning
# Binning of frames, default 1
amber.Parameters.binning=10
```

In this example, the parameter `amber.Parameters.binning` is set to the value 10. In the configuration file generated by *EsoRex*, one or more comment lines are added containing information about the possible values of the parameter, and an alias that could be used as a command line option (see again Section 5.5 on page 21).

The hierarchy introduced in the parameter names has currently no implication. Although it is not used at the moment, it is envisaged that this feature will be used in future releases to avoid potential name clashes. The shorter parameter aliases are made available for use on the command line.

The parameter names belonging to the recipe specific configuration files are described in the corresponding recipe sections.

More than one configuration file may be maintained for the same recipe but, in order to be used, a configuration file not located under `$HOME/.esorex`, or having a name different from the recipe name, must be explicitly specified when launching a recipe (see next section).

## 5.5 Running a recipe using EsoRex

The AMBER pipeline recipes are implemented as plugins executed by a front-end applications like *EsoRex* or *Gasgano* [7]. The file organizer *Gasgano* [7] provides an intuitive GUI for launching the recipes (and applying

<sup>1</sup>The plugin concept allows the implementation of different front-end applications with specific functionality. For a complete description on how to create a pipeline recipe launcher, please refer to the CPL User Manual [6].

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the same rules used by the DO for the available data frames classification), whereas *EsoRex* allows to execute the pipeline recipes from a shell prompt.

The basic format for using *EsoRex* is as follows:

```
esorex [EsoRex_options] recipe_name [recipe_options] set_of_frames
```

A list of all the available recipes, each with a one-line description, can be obtained using the command:

```
esorex --recipes
```

To get help for an individual recipe (in the subsequent examples, *amber\_SciCal* is used), the following is used:

```
esorex --help amber_SciCal
```

In order to see the current parameters setting of a recipe, either the recipe configuration file (if available) located under `$HOME/.esorex` may be viewed, or the following command may be used:

```
esorex --params amber_SciCal
```

If the default recipe configuration file is not found or a particular value is not configured within this file, then the system defaults will be shown and used.

A recipe can be run by specifying its name to *EsoRex*, together with the name of a SOF (see Section 5.3, page 20). For instance, the following command line would be used to run the recipe *amber\_SciCal* for processing the files specified in the SOF *amber\_SciCal.sof*:

```
esorex amber_SciCal amber_SciCal.sof
```

A recipe configuration file different from the default one (see Section 5.4, page 21) can also be specified on the command line:

```
esorex --recipe-config=my_alternative_config.rc amber_SciCal amber_SciCal.sof
```

The recipe parameters can be modified either by editing directly the used configuration file, or by specifying new parameter values on the command line using the command line options. Such command line options should be inserted after the recipe name, and before the SOF name. For instance, to set the *amber\_SciCal* recipe *binning* parameter to 10, the following should be typed:

```
esorex amber_SciCal --binning=10 amber_SciCal.sof
```

There are also parameters used to configure the *EsoRex* launcher, that may be listed in an *esorex.rc* configuration file located under `$HOME/.esorex`. On the command line, the *EsoRex* options must be inserted before, and not after, the specified recipe name. The *EsoRex* options are those that are recipe independent, as for instance the verbosity level, the directory where the recipe products should be written, or the permission to overwrite old products with new ones.

For more information on *EsoRex*, see <http://www.eso.org/cpl/esorex.html>.

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## 5.6 Running a complete data reduction using GASGANO

For AMBER we need a two step data reduction: First a P2VM must be derived and with that P2VM we can then reduce the scientific data taken with the same optical train.

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## 5.7 Creating a primary FITS-Image of the Channels

The recipe *amber\_raw\_to\_fitsimage* is able to display one AMBER raw frame at a time. Any rawframe listed in Table 5.7.1 can be used by the recipe. One can run the recipe in Gasgano by right clicking on a frame and choosing *amber\_raw\_to\_fitsimage*

The recipe will store the FITS-image at the location */tmp/amber\_raw\_to\_fitsimage.fits*. It can then be displayed by any suitable FITS viewer, i.e. the *FV*.

DO category	Type	Explanation	Required
AMBER_2P2V	Raw frame	2 telescopes P2VM	
AMBER_2WAVE	Raw frame	2 telescopes P2VM, spectral calibration	
AMBER_3P2V	Raw frame	3 telescopes P2VM	
AMBER_3WAVE	Raw frame	3 telescopes P2VM, spectral calibration	
AMBER_DARK	Raw frame	dark frame from scientific observation	
AMBER_SKY	Raw frame	sky frame from scientific observation	
AMBER_SCIENCE	Raw frame	science object frame from scientific observation	
AMBER_CALIB	Raw frame	calibrator object frame from scientific observation	
AMBER_BEAMPOS	Raw frame	beam position in various optical configurations for QC purpose	

Table 5.7.1: *Input files for the amber\_raw\_to\_fitsimage recipe.*



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## 5.8 Calculating the Pixel-To-Visibility-Matrix

This recipe will calculate the Pixel-To-Visibility-Matrix for a given optical setup of AMBER. It is needed as an input for all subsequent calculations of visibilities later on. Please note that a P2VM is only valid as long as the optical train stays unchanged. For this reason the P2VM raw files (see Table 5.8.1 for a list) have to be taken right before the scientific observation.

DO category	Type	Explanation	Required
AMBER_BADPIX	Calibration frame	Bad Pixel Map of the detector	✓
AMBER_FLATFIELD	Calibration frame	Flat Field of the detector and the instrument's optical train	✓
AMBER_2P2V	Raw frame	2 telescopes P2VM, 5 frames are needed	✓
AMBER_2WAVE	Raw frame	2 telescopes P2VM, spectral calibration	
AMBER_3P2V	Raw frame	3 telescopes P2VM, 10 frames are needed	✓
AMBER_3WAVE	Raw frame	3 telescopes P2VM, spectral calibration	

Table 5.8.1: *Input files for the amber\_p2vm recipe.*

Please note that the input of spectral calibration files is optional. If there are no spectral calibration files, the product will contain the spectral calibration values as they were during data acquisition.

A screen-shoot of Gasgano launching the amber\_p2vm recipe is displayed in Figure 5.8.1.

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amber\_p2vm v20001

File Help

Current Queued Executing

Parameters

Name	Value	Default	Range
amber.amber_p2vm.dummy			

Input Frames

Include	Filename	Classification		
<input checked="" type="checkbox"/>	AMBER.2006-02-11T00:25:39.341.fits	AMBER_2WAVE	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T00:25:51.000.fits	AMBER_2WAVE	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T00:26:08.457.fits	AMBER_2WAVE	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T00:26:39.319.fits	AMBER_2P2V	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T00:26:54.079.fits	AMBER_2P2V	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T00:27:18.478.fits	AMBER_2P2V	Locate	Display

Product Naming

Product Root Directory: /home/tlicha/amdlib\_test/products Browse Naming Scheme: Numeric

Execute

Add to pool

Request Pool

Execute Selected

Output Frames

Clear

Log Messages

Save Clear

Figure 5.8.1: The recipe *amber\_p2vm* when launched with *GASGANO*.

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## 5.9 Calculating the scientific results

The AMBER pipeline recipe *amber\_SciCal* is used to calculate visibilities from interferometric observations.

This recipe is able to handle 2- and 3-telescope observations. The DET NTEL keyword from the first rawfile's header will determine the mode. It can also handle all the different bands (JHK) in any resolution. If there is more than one band present in the raw frame the recipe will split the bands and create a separate product file for the J, H, and K band, respectively.

All the files that must/can be included in the input SOF are listed in Table 5.9.1. In addition to the frames marked as required there must be at least one frame of the DO categories AMBER\_SCIENCE, AMBER\_CALIB or AMBER\_SCIENCE\_CALIB. For each of them the corresponding product will be created.

DO category	Type	Explanation	Required
AMBER_BADPIX	Calibration frame	Bad Pixel Map of the detector	✓
AMBER_FLATFIELD	Calibration frame	Flat Field of the detector and the instrument's optical train	✓
AMBER_P2VM	Calibration frame	Pixel-To-Visibility-Matrix of the instrument's optical train	✓
AMBER__DARK	Raw frame	dark frame from scientific observation	
AMBER__SKY	Raw frame	sky frame from scientific observation	
AMBER_SCIENCE	Raw frame	science object frame from scientific observation	✓
AMBER_CALIB	Raw frame	calibrator object frame from scientific observation	
AMBER_SCIENCE_CALIB	Raw frame	standard calibrator object frame	

Table 5.9.1: *Input files for the amber\_SciCal recipe.*

A screen-shoot of Gasgano launching the *amber\_SciCal* recipe is displayed in Figure 5.9.1.

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amber\_SciCal v20001

File Help

Current Queued Executing

Parameters

Name	Value	Default	Range
amber.amber_SciCal.str_option			
amber.amber_SciCal.int_binning	50	1	

Input Frames

Include	Filename	Classification	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T05:13:36.596.fits	AMBER_P2VM	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T06:11:30.007.fits	AMBER_SCIENCE_DARK	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T06:13:29.571.fits	AMBER_SCIENCE	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T06:14:57.175.fits	AMBER_SCIENCE	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T06:16:48.723.fits	AMBER_SCIENCE	Locate	Display
<input checked="" type="checkbox"/>	AMBER.2006-02-11T06:18:24.260.fits	AMBER_SCIENCE	Locate	Display
<input checked="" type="checkbox"/>	AMBER_BPM_fuzzy_img.fits	AMBER_BADPIX	Locate	Display
<input checked="" type="checkbox"/>	AMBER_FFM_img.fits	AMBER_FLATFIELD	Locate	Display

Product Naming

Product Root Directory: /home/tlicha/amdlib\_test/products Browse Naming Scheme: Numeric

Execute

Add to pool

Request Pool

Execute Selected

Output Frames

Clear

Log Messages

Save Clear

Figure 5.9.1: The recipe *amber\_SciCal* when launched with *GASGANO*.

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## 5.10 Plotting the scientific results

It is possible to plot the scientific results from previously stored products (GASGANO will group the product at the end of the raw files of the observation so that they can easily be identified): First a particular product must be selected and right clicked. After that, "Run..." must be chosen in the menu. Selecting 'amber\_OI\_FITS\_plot.sh' will finally start the plotting routine (see also Figure 5.10.1). Please make sure that MIDAS is installed and that the `amber_OI_FITS_plot.prg` resides in the same path as the script.

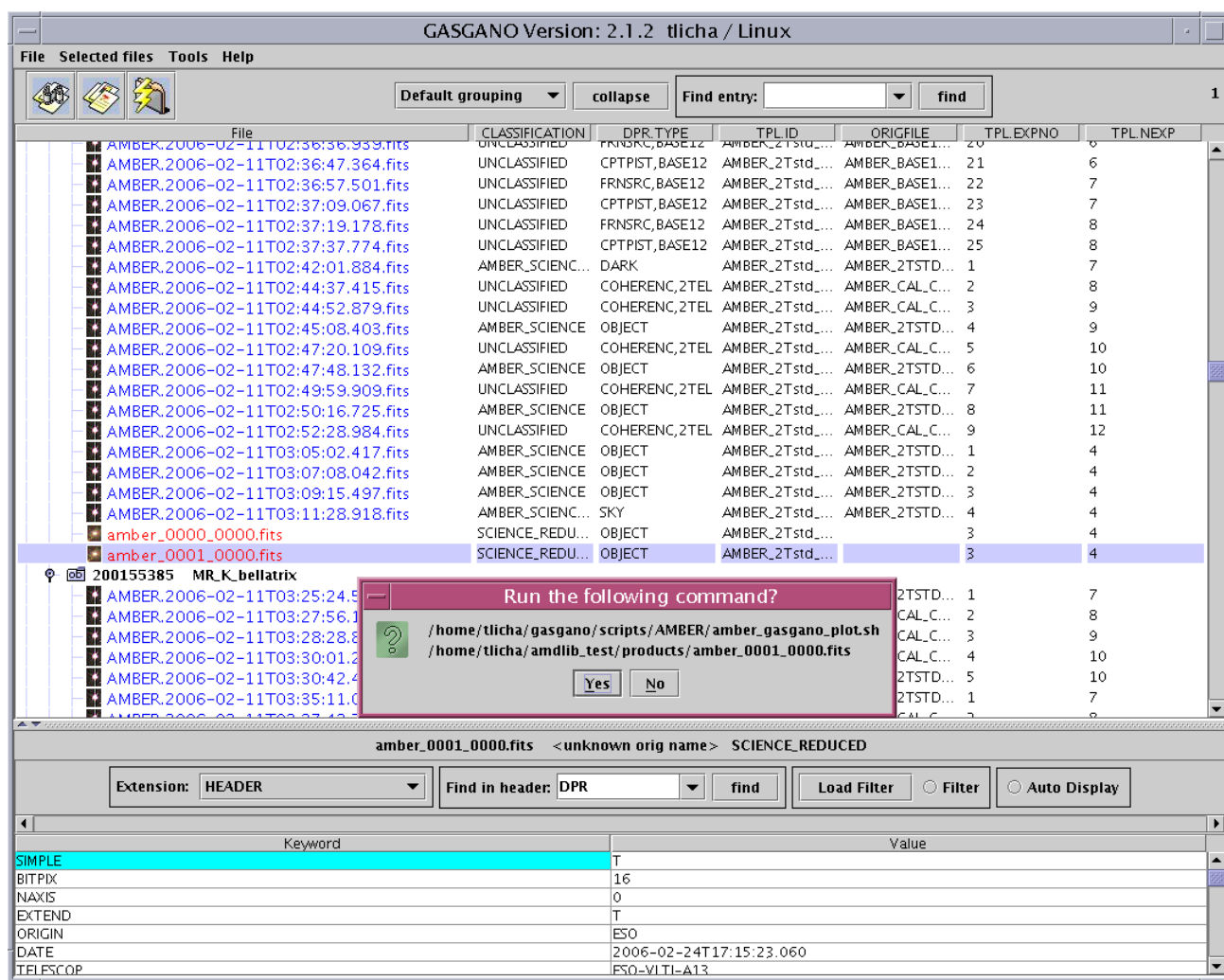


Figure 5.10.1: Starting the plotting script from GASGANO

To finish the plot and return to GASGANO one has to type *bye* in the window named *inmidas*. After the plot has completed on the screen there is the corresponding post script file available: `/tmp/amber_0000.ps`. As the post script file will be overwritten each time by the next plot, one has to rename it or copy it to another directory for further usage.

Please note that the plots are different for the 2 and 3 telescopes case as in the 3 telescopes case there are 3



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## 6 Pipeline Recipes Interfaces

### 6.1 amber-raw-to-fitsimage

The AMBER pipeline recipe *amber\_raw\_to\_fitsimage* creates a primary image from AMBER rawfiles which only contain tables of numbers. The image can be regarded as a recreation of the active CCD area. Any of the AMBER raw frames can be displayed with the recipe (it can handle raw files taken in 2 and 3 telescope mode). The recipe is very useful to check if the interferometric channel is actually showing fringes and if flux is present in all photometric channels. At least one of the files listed in Table 6.1.1 must be included in the SOF. If there are more files only the first one will be displayed. As an example we show in Figure 6.1.1 the vertically dispersed channels of the AMBER instrument.

DO category	Type	Explanation	Required
AMBER_2P2V	Raw frame	2 telescopes P2VM	
AMBER_2WAVE	Raw frame	2 telescopes P2VM, spectral calibration	
AMBER_3P2V	Raw frame	3 telescopes P2VM	
AMBER_3WAVE	Raw frame	3 telescopes P2VM, spectral calibration	
AMBER_DARK	Raw frame	dark frame from scientific observation	
AMBER_SKY	Raw frame	sky frame from scientific observation	
AMBER_SCIENCE	Raw frame	science object frame from scientific observation	
AMBER_CALIB	Raw frame	calibrator object frame from scientific observation	
AMBER_BEAMPOS	Raw frame	beam position in various optical configurations for QC purpose	

Table 6.1.1: *Input files for the amber\_raw\_to\_fitsimage recipe.*

File name	DO category	Type	Explanation
/tmp/amber_display.fits		FITS	reconstructed image of the active detector regions

Table 6.1.2: *Output of the amber\_raw\_to\_fitsimage recipe.*

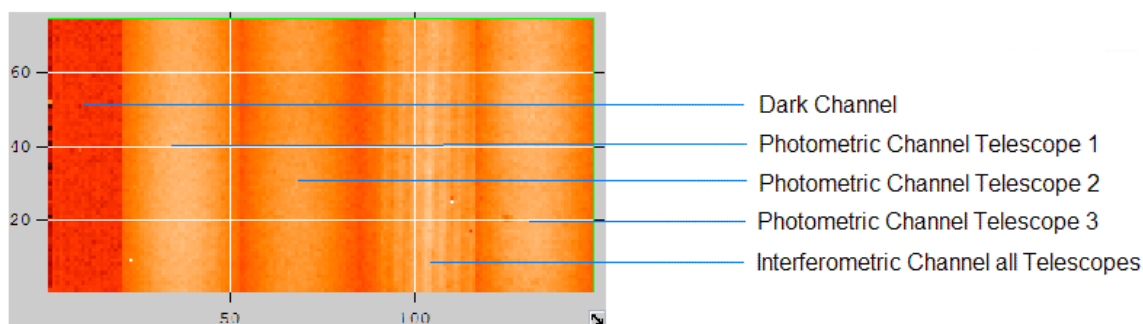


Figure 6.1.1: *Example image for the 3-telescopes mode.*

The recipe creates a FITS file containing the primary image of the reconstructed image of the active detector

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regions. In addition the header is completed with a copy of the raw frame's header to describe the frame. A copy of the product will always be stored with the fixed name /tmp/amber\_display.fits (see Table 6.1.2).

There are no *amber\_raw\_to\_fitsimage* parameters.

## 6.2 amber-detector

The AMBER pipeline recipe *amber\_detector* is used to create the bad pixel map and the master flat field for the AMBER instrument. A detailed description of the used algorithms is given in Appendix B on page 44.

The files listed in Table 6.2.1 must be included in the SOF when running the recipe.

DO category	Type	Explanation	Required
AMBER_DETECTOR_DARK	Raw frame	dark exposure	✓
AMBER_DETECTOR_FFM	Raw frame	flat exposure	✓

Table 6.2.1: *Input files for the amber\_detector recipe.*

The product written by the *amber\_detector* recipe is listed in Table 6.2.2, whereas the QC parameters are listed in Table 6.2.3

File name	DO category	Type	Explanation
amber_eso_bpm.fits	AMBER_BADPIX	FITS	Bad pixel map
amber_eso_ffm.fits	AMBER_FLATFIELD	FITS	Master flat field

Table 6.2.2: *Product of the amber\_detector recipe.*

QC Parameter	Explanation
BADPIX	the number of bad pixels on the chip
GOODPIX	the number of good pixels on the chip

Table 6.2.3: *QC values written by amber\_detector recipe.*



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### 6.3 amber-beampos

The AMBER pipeline recipe *amber\_beampos* is used to monitor the beam alignment for the AMBER instrument. A technical template of the AMBER instrument will create the 22 mandatory files to run the recipe (see also Table 6.3.1). These files contain an image of the AMBER instrument beam under various illumination conditions. From these files the recipe will derive an image of the detector as well as QC parameters and write them to a product as well as to the QC log. The product written by the *amber\_beampos* recipe is listed in Table 6.3.2

For each of the frames the QC values listed in Table 6.3.3 are written. Depending on the type of the frame there will be a prefix (see Table 6.3.4) written to identify the specific optical configuration, i.e. a complete QC parameter including the prefix would read:

*HIERARCH.ESO.QC.CLDSTP.SIZX=23.45*

DO category	Type	Explanation	Required
AMBER_BEAMPOS	Raw frame	exposures with different optic-settings	✓

Table 6.3.1: *Input files for the amber\_beampos recipe.*

File name	DO category	Type	Explanation
amber_beampos_XXX.fits	AMBER_BEAMPOS_REDUCED	FITS	FITS file with primary image of the beam and the QC parameters in the header (XXXX corresponds to the raw file's number)

Table 6.3.2: *Product of the amber\_beampos recipe.*

QC Parameter	Explanation
X	the x position of the beam centroid
Y	the y position of the beam centroid
SIZX	the size in x direction of the beam
SIZY	the size in y direction of the beam
FLUX	the total flux of the beam
PEAKFLUX	the peak flux of the beam

Table 6.3.3: *QC values written by the amber\_beampos recipe.*

Please note that this recipe currently relies on the correct order of the frames given in the Set of Frames. This will not be a problem for the online pipeline unless the acquisition template might be changed. In GASGANO the user should send the files in the order given by the entry of the header named TPL.EXPNO.

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QC Prefix	Explanation
CLDSTP	cold stop
A.K	A in K band
B.K	B in K band
C.K	C in K band
A.H	A in H band
B.H	B in H band
C.H	C in H band
A.J	A in J band
B.J	B in J band
C.J	C in J band
BCD.A.K	BCD and A in K band
BCD.B.K	BCD and B in K band
BCD.C.K	BCD and C in K band
BCD.A.H	BCD and A in H band
BCD.B.H	BCD and B in H band
BCD.C.H	BCD and C in H band
BCD.A.J	BCD and A in J band
BCD.B.J	BCD and B in J band
BCD.C.J	BCD and C in J band
OUTF.A	OUTF and A
OUTF.B	OUTF and B
OUTF.C	OUTF and C

Table 6.3.4: *QC value prefixes written by the amber\_beampos recipe.*

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## 6.4 amber-p2vm

The AMBER pipeline recipe *amber\_p2vm* is used to create a pixel to visibility matrix (P2VM). This P2VM is containing the translation matrix for the interferometric channel used to calculate visibilities from scientific observations. The recipe is able to handle 2- and 3-telescope P2VMs, where the DET NTEL keyword from the first rawfile's header will determine the mode. A more detailed description of the algorithms is given in Appendix B on page 44.

At the moment there are no *amber\_p2vm* recipe parameters.

The raw files are containing all possible variations of the shutter positions of the photometric channels and the response of the interferometric channel for the standard lamps used during that process. Because in 3-telescope mode there is one more photometric channel compared to the 2 telescope mode, more input files are needed (10 instead of 5). The files listed in Table 6.4.1 can/must be used in the SOF when running the recipe.

DO category	Type	Explanation	Required
AMBER_BADPIX	Calibration frame	Bad Pixel Map of the detector	✓
AMBER_FLATFIELD	Calibration frame	Flat Field of the detector and the instrument's optical train	✓
AMBER_2P2V	Raw frame	2 telescopes P2VM, 5 frames are needed	✓
AMBER_2WAVE	Raw frame	2 telescopes P2VM, spectral calibration	
AMBER_3P2V	Raw frame	3 telescopes P2VM, 10 frames are needed	✓
AMBER_3WAVE	Raw frame	3 telescopes P2VM, spectral calibration	

Table 6.4.1: *Input files for the amber\_p2vm recipe.*

The only product of the *amber\_p2vm* recipe is the P2VM file (see Table 6.4.2).

File name	DO category	Type	Explanation
amber_p2vm.fits	P2VM_REDUCED	FITS	Pixel to Visibility Matrix

Table 6.4.2: *Product of the amber\_p2vm recipe.*

This recipe is writing the QC parameters listed in Table 6.4.3.

QC Parameter	Explanation
P1 OFFSETY	y offset after spectral calibration in pixels for photometric channel 1
P2 OFFSETY	y offset after spectral calibration in pixels for photometric channel 2
P3 OFFSETY	y offset after spectral calibration in pixels for photometric channel 3

Table 6.4.3: *QC values written by the amber\_p2vm recipe.*

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## 6.5 amber-SciCal

The AMBER pipeline recipe *amber\_SciCal* is used to calculate raw (uncalibrated) visibilities from interferometric observations. This recipe is able to handle 2- as well as 3-telescope observations. The DET NTEL keyword from the first rawfile's header will determine the mode. It can handle all the different bands in any resolution. If there is more than one band in the raw frame the recipe will split the bands and create a separate product for the J, H and K band. A description of the algorithms used in this recipe is given in Appendix B on page 44.

All the files that must be included in the input SOF are listed in Table 6.5.1. In addition to the frames marked as required there must be at least one frame of the DO categories AMBER\_SCIENCE or AMBER\_CALIB (and AMBER\_SCIENCE\_CALIB for backwards compatibility). For each of them a corresponding product will be created.

DO category	Type	Explanation	Required
AMBER_BADPIX	Calibration frame	Bad Pixel Map of the detector	✓
AMBER_FLATFIELD	Calibration frame	Flat Field of the detector and the instrument's optical train	✓
AMBER_P2VM	Calibration frame	Pixel-To-Visibility-Matrix of the instrument's optical train	✓
AMBER_DARK	Raw frame	dark frame from scientific observation	
AMBER_SKY	Raw frame	sky frame from scientific observation	
AMBER_SCIENCE	Raw frame	science object frame from scientific observation	✓
AMBER_CALIB	Raw frame	calibrator object frame from scientific observation	

Table 6.5.1: *Input files for the amber\_SciCal recipe.*

The only product of the *amber\_SciCal* recipe is an OI file (see Table 6.5.2).

File name	DO category	Type	Explanation
amber_XXXX.fits	SCIENCE_REDUCED	FITS	OI FITS file, with XXXX corresponding to the file's number

Table 6.5.2: *Product of the amber\_SciCal recipe.*

The *amber\_SciCal* parameters are listed in Table 6.5.3.

Parameter	Possible values	Explanation
binning	0 to 9999 (maximum number of frames per observation)	the number of frames to be averaged for each of the visibility calculations

Table 6.5.3: *amber\_SciCal parameters.*

This recipe is writing the QC parameters listed in Table 6.5.4.

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QC Parameter	Explanation
FRAMES SELECTED SNRGT2	the number of frames with signal to noise greater than 2
FRAMES SELECTED PERCENT	the percentage of frames with signal to noise greater than 2
FRAMES BAND	the band (J, H, K)
STA1	telescope station 1
STA2	telescope station 2
STA3	telescope station 3 (in 3 telescopes mode only)

Table 6.5.4: *QC values written by the amber\_SciCal recipe.*

## 6.6 amber-selector

The AMBER pipeline recipe *amber\_selector* is used to select matching frames from AMBER products created by *amber\_SciCal* (see Table 6.5.2 and Table 6.6.1). The output is again an AMBER product (same OI FITS format like the input) but will only contain the matching frames which passed the filter. This means the resulting product can be plotted by the same tools like all other AMBER OI FITS files.

Please note that in three telescopes mode we will of course have three baselines. In the OI fits standard they have to be written in a sequence of triples like {base1, base2, base3}, {base1, base2, base3}, ... . To maintain consistency the whole triple has to be written even if only *ONE* visibility matches a certain selection. In other words the written product can still contain visibilities which actually did not match the selection!!

DO category	Type	Explanation	Required
SCIENCE_REDUCED	product frame	OI FITS file	✓
CALIB_REDUCED	product frame	OI FITS file	✓

Table 6.6.1: *Input files for the amber\_selector recipe.*

There are various algorithms to select and filter the data. The algorithms can be selected and controlled by the parameters *selection\_method* and *selection\_x*.

The different selection methods are:

- **First x Frames:** This method will filter the first x frames of the observation. The purpose of this method is a more technical one. It can be used to check if the instrument is properly suppressing the very first few frames after switching the detector to ON. These frames usually contain garbage due to the design of the readout electronics of the detector.
- **Fringe SNR > x:** This method is using the amdlib method amdlibFRG\_CONTRAST\_SEL\_THR. It loops through all visibilities of all baselines. If the corresponding fringe SNR is greater than the threshold x, this visibility will be included into the selection. Please note that in 3 telescopes mode the OI FITS standard requires to write all three visibilities of the 3 baselines, even if only one visibility exceeds the threshold.
- **Fringe SNR percentage x:** This method is using the amdlib method amdlibFRG\_CONTRAST\_SEL\_PCG. Currently not working to satisfaction and under construction.

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- **Flux > x:** This method is using the amdlib method `amdlibFLUX_SEL_THR`. Currently not working to satisfaction and under construction.
- **Flux percentage x:** This method is using the amdlib method `amdlibFLUX_SEL_PCG`. Currently not working to satisfaction and under construction.
- **Exclude Frames by ASCII File:** This method is an interface to external tools which are able to identify frames to be excluded. The usage is quite simple: one only has to store a file called `/tmp/amber_exclude.txt` containing the frame index (there shall be only one frame index per line). For example, if you want to exclude frame number 13, 20, 25 and 255 the file should look as shown in Table 6.6.2. The output of the recipe is a OI FITS file which contains all frames but not the four listed before.
- **Include Frames by ASCII File:** This method works very similar as the exclude method described before. It will keep the frames with the given index numbers and drop all the rest. The file must be called `/tmp/amber_include.txt`
- **IO-Test: no filtering:** This is for testing only. It will read the whole input to internal structures and write it back unchanged.

13
20
25
255

Table 6.6.2: Example of the file `/tmp/amber_exclude.txt`.

## 6.7 amber-divider

The AMBER pipeline recipe `amber_divider` is used to create calibrated visibilities from AMBER products created by `amber_SciCal`. One product must be from a calibrator object and the other from a science object (see Table 6.7.1). This recipe can be used as a template for own implementation and is currently only implemented in order to give the proper interface.

DO category	Type	Explanation	Required
SCIENCE_REDUCED	product frame	OI FITS file	✓
CALIB_REDUCED	product frame	OI FITS file	✓

Table 6.7.1: Input files for the `amber_divider` recipe.

## 6.8 amber-ascii-export

The AMBER pipeline recipe `amber_ascii_export` is part of the distribution but not supported by ESO. It was kindly provided by Klara Shabun. Please contact her directly for any questions on the recipe.

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## 7 Product Data Description

Products can be classified as *intermediate product* or *scientific product*. They are classified by the DO or by *Gasgano* [7] according to their own DO category (keyword `PRO CATG`) assigned at creation time. For this reason no classification keyword is listed in this section. The name of the recipe (or recipes) used to create a given product is given.

### 7.1 Intermediate Products

- **Flat Field:**

DO category: `AMBER_FLATFIELD`

Created by: `amber_detector`

Association keywords:

`DET NTEL`

Note:

Number of Telescopes used

- **Bad Pixel Map:**

DO category: `AMBER_BADPIX`

Created by: `amber_detector`

Association keywords:

`DET NTEL`

Note:

Number of Telescopes used

- **Pixel-To-Visibility-Matrix P2VM:**

DO category: `P2VM_REDUCED`

Created by: `amber_p2vm`

Association keywords:

`DET NTEL`

Note:

Number of Telescopes used

- **Beam Position:**

DO category: `BEAMPOS_REDUCED`

Created by: `amber_BeamPos`

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## 7.2 Scientific Products

- **OI Science Product:**

DO category: SCIENCE\_REDUCED

Created by: amber\_SciCal

Association keywords:

DET NTEL

Note:

Number of Telescopes used

- **OI Calibrator Product:**

DO category: CALIB\_REDUCED

Created by: amber\_SciCal

Association keywords:

DET NTEL

Note:

Number of Telescopes used



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## A Installation

This chapter gives generic instructions on how to obtain, build and install the AMBER pipeline. Even if this chapter is kept as up-to-date as much as possible, it may not be fully applicable to a particular release. This might especially happen for patch releases. One is therefore advised to read the installation instructions delivered with the AMBER pipeline distribution kit. These release-specific instructions can be found in the file `README` located in the top-level directory of the unpacked AMBER pipeline source tree. The supported platforms are listed in Section A.1. It is recommended reading through Section A.2.2 before starting the installation.

A bundled version of the AMBER pipeline with all the required tools and an installer script is available from <http://www.eso.org/pipelines/>, for users who are not familiar with the installation of software packages.

### A.1 Supported platforms

The utilization of the GNU build tools should allow to build and install the AMBER pipeline on a variety of UNIX platforms, but it has only been verified on the VLT target platform:

- Linux (glibc 2.1 or later),

using the GNU C compiler (version 3.2 or newer).

### A.2 Building the AMBER pipeline

This section shows how to obtain, build and install the AMBER pipeline from the official source distribution.

#### A.2.1 Requirements

To compile and install the AMBER pipeline one needs:

- The GNU C compiler (version 3.2 or later)
- The GNU `gzip` data compression program
- A version of the `tar` file-archiving program
- The GNU `make` utility
- Perl
- Java Development Kit (if `gasgano` should be installed)

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### A.2.2 Compiling and installing the AMBER pipeline

The AMBER pipeline distribution kit 2.3.7 contains:

README	Installation instructions
AMBER_PipelineUserManual.pdf	The AMBER pipeline manual
install_pipeline	Install script
qfits-6.2.0.tar.gz	QFITS
cpl-3.1.tar.gz	CPL
esorex-3.6.1.tar.gz	esorex
gasgano-2.2.7.tar.gz	GASGANO
amber-2.3.7.tar.gz	AMBER source code
amber-calib-2.3.7.tar.gz	AMBER calibration files

Here is a description of the installation procedure:

1. Change directory to where you want to retrieve the AMBER pipeline package. It can be any directory of your choice but not:

```
$HOME/gasgano
$HOME/.esorex
```

2. Download from the ESO ftp server, <http://www.eso.org/pipelines/>, the latest release of the AMBER pipeline distribution.
3. Verify the checksum value of the tar file with the cksum command.
4. Unpack using the following command:

```
tar -xzf amber-kit-2.3.7.tar.gz
```

Note that the size of the installed software (including *Gasgano*) together with the static calibration data is about 15Mb.

5. Install: after moving to the top installation directory,

```
cd amber-kit-2.3.7
```

it is possible to perform a simple installation using the available installer script (*recommended*):

```
./install_pipeline
```

(beware: the execution may take a few minutes).

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By default the script will install the AMBER recipes, *Gasgano*, *EsoRex*, all the necessary libraries, and the static calibration tables, into a directory tree rooted at `$HOME`. A different path may be specified as soon as the script is run.

The only exception to all this is the *Gasgano* tool, that will always be installed under the directory `$HOME/gasgano`. Note that the installer will move an existing `$HOME/gasgano` directory to `$HOME/gasgano.old` before the new *Gasgano* version is installed.

Important: the installation script would ensure that any existing *Gasgano* and *EsoRex* setup would be inherited into the newly installed configuration files (avoiding in this way any conflict with other installed instrument pipelines).

Alternatively, it is possible to perform a manual installation (*experienced users only*): the `README` file located in the top installation directory contains more detailed information about a step-by-step installation.

Please note, that for the manual installation (*experienced users only*) it is important to include the options `--enable-type-prefix` `--enable-float` to the `configure` call in order to force the `fftw` subsystem to compile correctly. In case your box has already the package *scisoft* pre-installed you also have to add the `F77=` for proper compilation of AMBER pipeline. A typical configuration could look like that:

```
./configure --prefix=$CPLDIR --enable-type-prefix --enable-float F77=
```

On some 64-bit computers also the option `--with-pic` must be included.

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## B Algorithms

In this section the data reduction procedures applied by the pipeline recipes currently in use (see Section 5.2) are described in more detail. Common algorithms, as cosmic rays removal or bad pixel cleaning, are described separately.

### B.1 General Algorithms

#### B.1.1 Dark subtraction

Dark frames are taken during the actual observation run. If no dark is available, the dark channel (left most side on the CCD chip) will be used, instead. This will of course reduce the accuracy.

#### B.1.2 Bad Pixel Map and Flat Field Generation

The following paragraph was adopted from an article (private communication) by M. Heininger, MPI Bonn.

In order to generate all important detector characterization maps, several series of dark and flatfield images are necessary. Experiments have shown that at least 7 series with about 100 images are needed. The illumination level should reach 40 percent of the full well capacity. For example, if saturation is reached after 10 seconds, the recommended exposure times are 600, 1200, 1800, 2400, 3000, 3600, and 4200 ms. For each exposure time, 100 dark images and 100 flatfield images are necessary, adding up to 14 image series, each including 100 images (about 1.5 GBytes). These data requirements are fulfilled by the accompanying recipe.

In Figure B.1.1, a typical cold dark image is shown in the left panel and a typical flatfield image in the right panel. These images are influenced by detector, electronic, and environmental effects, which are highlighted in this figure. On the left side of the cold dark image, a damped oscillation can be seen. The electronic bias shows up as a vertical ramp. One particle event is marked in the dark image (this event is also shown in figures B.1.2 and B.1.3) and in the flatfield image. The nearby cluster of white pixels in the dark image is a cluster of bad pixels, which is found later on by the algorithms described further in this document. Several hot (white) and dark pixels are clearly visible in both images too. The flatfield image on the right shows the same effects as a cold dark image. In addition, the shielded area on the left side of the detector used for calibration purposes and the inhomogeneous illumination caused by the spectrograph are obvious.

All effects visible in Figure B.1.1 must be taken into account when generating a bad pixel map and a flatfield map:

- The damped oscillation and the electronic bias are stable enough to compensate them by using an electronic bias map which contains both effects in one map (see Appendix B.1.4).
- Particle events influence the temporal noise of pixels, and the images which contain such events must be ignored for the affected pixels.
- The shielded area is used to compensate the global detector offset and the 1/f noise (not visible in Figure B.1.1).

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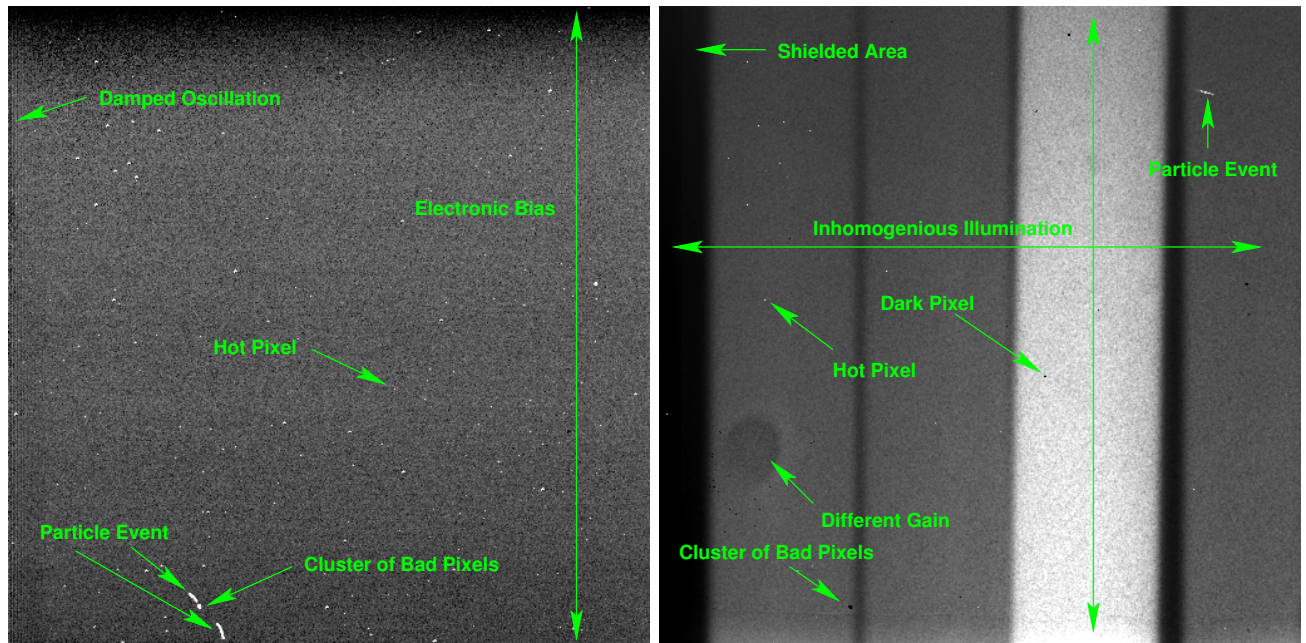


Figure B.1.1: Typical cold dark image on the left and a typical flatfield image on the right.

- The inhomogeneous illumination must be taken into account when calculating the flatfield map because the flatfield map must only contain the different pixel gain.

In order to generate a bad pixel map and a flatfield map the pipeline performs the following tasks:

1. For each series of dark images, a particle event map, an electronic bias map, a pixel bias map, and a pixel statistics map is generated (see Appendix [B.1.3](#), [B.1.4](#), and [B.1.5](#)).
2. For each series of flatfield images, a particle event map, a photon noise map, and a pixel statistics map is generated (see Appendix [B.1.3](#) and [B.1.5](#)). For this step, the pixel bias maps and the electronic bias maps from the corresponding series of dark images are used.
3. A dark current map from the pixel statistics maps of all series of dark images is generated (see Appendix [B.1.6](#)).
4. A bad pixel map is generated using the pixel statistics maps, photon noise maps, and dark current map (see Appendix [B.1.7](#)).
5. New pixel statistics maps for the series of flatfield images with compensation for pixel bias, electronic bias, and particle events are generated.
6. A flatfield map from the new pixel statistics maps for the series of flatfield images is generated (see Appendix [B.1.8](#)).

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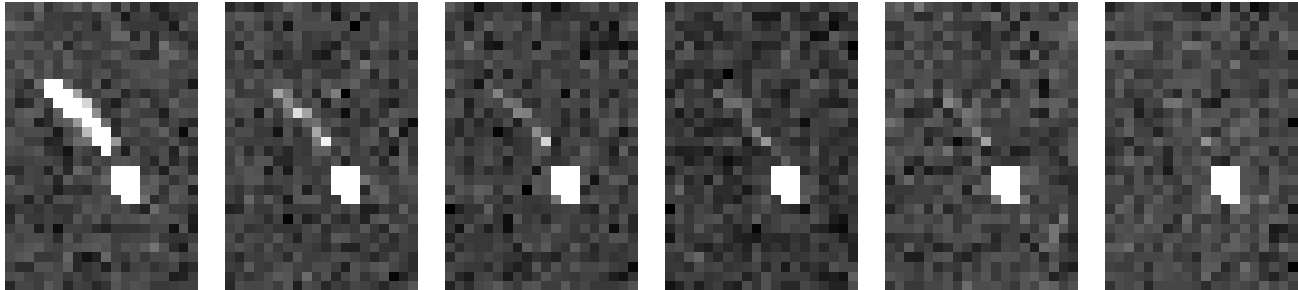


Figure B.1.2: A particle event and afterglow on the detector

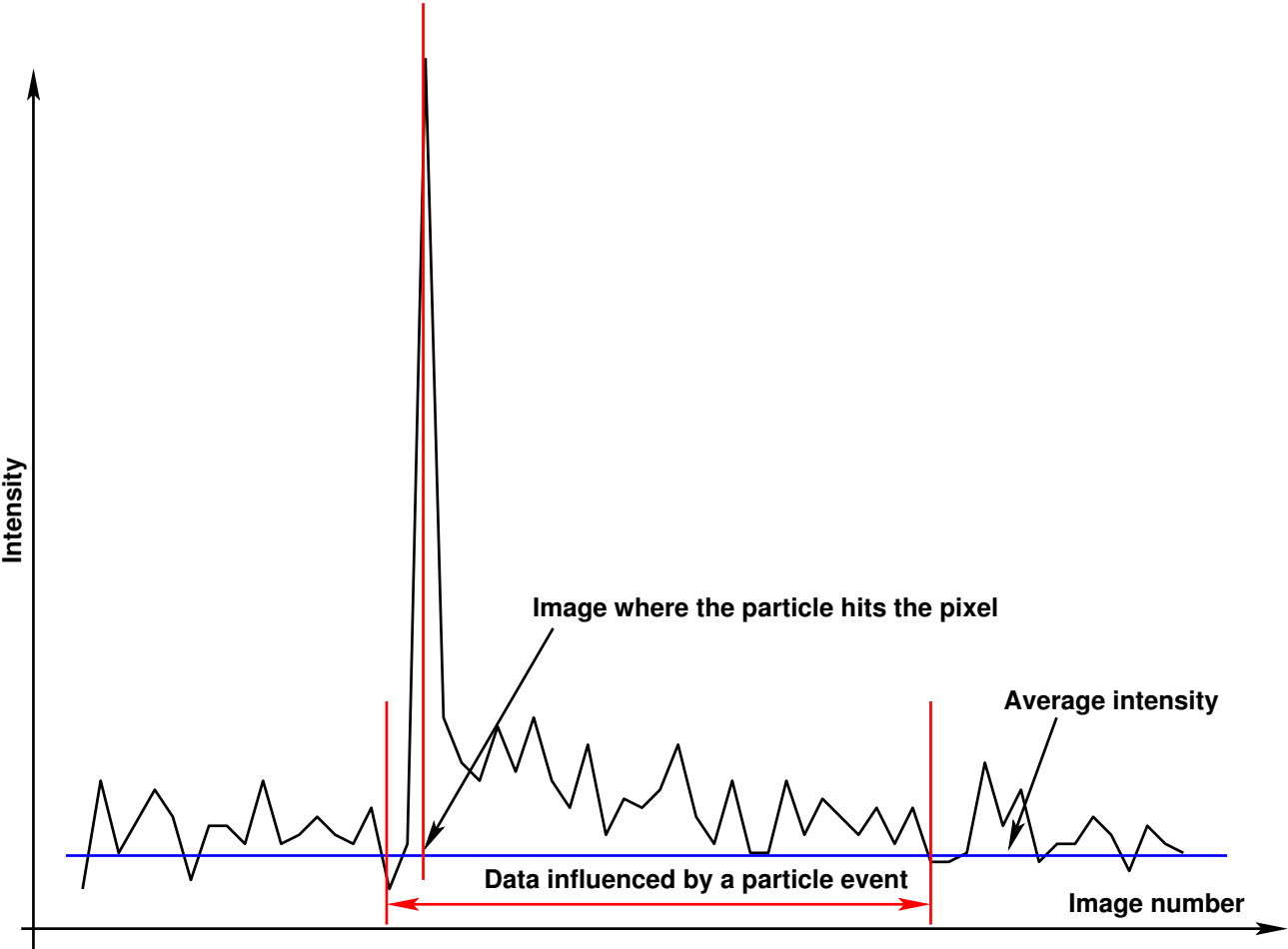


Figure B.1.3: Intensity values of a pixel during a particle event with afterglow

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### B.1.3 Particle Events

Images taken with the HAWAII-1 detector of the AMBER instrument show random particle events at a rate of about 2 events per quadrant per minute exposure time. This rate seems to be independent of the observing site because images taken in Bonn show the same number of events per minute. These particle events show up as a sudden raise in the intensity of a few pixels. Normally, these pixels build a small cluster of 2-20 pixels. After a few images, the intensity of these pixels drops to the previous value.

In Figure B.1.2 a particle event is shown, where the left panel shows the image when the particle hits the detector. The other panels show the afterglow of the event. The permanently visible cluster is a small cluster of defect pixels on the AMBER detector (chip #159). Figure B.1.3 shows the intensity variations of a pixel during that particle event.

The *amdms* library implements an algorithm which detects particle events under the following conditions:

- More than one pixel is influenced.
- These pixels are connected, which means they are direct neighbors.
- The raise in intensity is larger than a given limit.

If a pixel is influenced by a particle event, the average intensity and the variance has to be recalculated by ignoring the affected images. The algorithm used for the particle event detection is implemented as a filter. This means a pixel has to pass certain tests before a particle event influencing this pixel is accepted and a new mean and variance is calculated:

```

Try to detect particle events, mark the affected images, and recalculate the statistics.
PROC amdmsDetectParticleEvents()
  try to find candidates for particle events (see amdmsFindPEs())
  allocate memory for all candidate pixels and their data values;
  reload the data values for all candidate pixels;
  FOR EACH candidate pixel DO
    analyze the candidate pixel (see amdmsAnalyzePE());
    IF the pixel is still a candidate THEN
      find the affected image interval (see amdmsFindPEInterval());
    ENDIF
  ENDFOR
  FOR EACH candidate pixel DO
    try to verify the particle event (see amdmsVerifyPE());
  ENDFOR
  FOR EACH candidate pixel DO
    recalculate the mean and variance (see amdmsRecalculateMeanVar());
  ENDFOR
ENDPROC

```

Candidate pixels are found by comparing the measured variance with a given limit. For cold dark images, this limit is equal to a noise of  $40e^-$ ; for flatfield images this limit is equal to a noise of  $100e^-$ . It is also necessary that at least one nearby pixel has a variance which is higher than this limit. This means that isolated pixels with an unusually high variance are treated as bad pixels. It is still possible that a particle event affected only one pixel; in this case that event is not detected, but the pixel is marked as a bad pixel.

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*Try to find candidates for particle events.*

```
PROC amdmsFindPEs()
  FOR EACH pixel DO
    IF the variance of this pixel is less than the limit THEN CONTINUE ENDIF
    IF no nearby pixel shows a variance higher than the limit THEN CONTINUE ENDIF
    mark this pixel as a possible candidate for a particle event;
  ENDFOR
ENDPROC
```

To distinguish between really bad pixels with a high variability and pixels affected by particle events, the following function calculates the mean and variance for the first half and the second half of the pixel values. If there is no significant difference in the variance of both half, the pixel is marked as a bad pixel.

*Analyze the data of one candidate pixel, which means try to locate the particle event in the first or second half of the data values of a pixel.*

```
PROC amdmsAnalyzePE(candidate pixel)
  calculate mean ( $m$ ) and variance ( $v$ ) for all data values;
  set a split point at the middle of the data set;
  calculate mean ( $m_f$ ) and variance ( $v_f$ ) from 0 up to the split point;
  calculate mean ( $m_s$ ) and variance ( $v_s$ ) from the split point up to the end;
  IF  $v_f < 0.5v$  AND  $v_s > 1.5v$  THEN
    // the particle event is in the second half of the data, mean and variance are
    // recalculated by moving the split point by -20 images (enlarge the second part)
    recalculate mean ( $m_f$ ) and variance ( $v_f$ ) from 0 up to the split point;
    recalculate mean ( $m_s$ ) and variance ( $v_s$ ) from the split point up to the end;
    IF  $v_f < 0.5v$  AND  $v_s > 1.5v$  THEN
      // the particle event could be verified in the second part of the data
      store the split point and the end of the data as interval of a particle event;
    ELSE
      remove this candidate pixel from the list;
    ENDIF
  ELSEIF  $v_s < 0.5v$  AND  $v_f > 1.5v$  THEN
    // the particle event is in the first half of the data, mean and variance are
    // recalculated by moving the split point by +20 images (enlarge the first part)
    recalculate mean ( $m_f$ ) and variance ( $v_f$ ) from 0 up to the split point;
    recalculate mean ( $m_s$ ) and variance ( $v_s$ ) from the split point up to the end;
    IF  $v_s < 0.5v$  AND  $v_f > 1.5v$  THEN
      // the particle event could be verified in the first part of the data
      store the split point and the end of the data as interval of a particle event;
    ELSE
      remove this candidate pixel from the list;
    ENDIF
  ELSE
    remove this candidate pixel from the list;
  ENDIF
ENDPROC
```

As shown in Figure B.1.3, the following procedure tries to find the interval of images where the particle hit the pixel and the afterglow of the event affected the measured intensity.



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*Find the images which are affected by the particle event (see Figure B.1.3).*

```
PROC amdmsFindPEInterval(candidate pixel)
  find the peak value inside the interval;
  find the image before the peak where the value is below the mean  $m$ ;
  find the image after the peak where the value is below the mean  $m$ ;
  store the first and last image of this interval;
ENDPROC
```

The final test for a candidate pixel is that the interval of the affected images of this pixel and a nearby candidate pixel must overlap. If this is not the case, the pixel is treated as a bad pixel. If there is an overlap, both pixels are treated as pixels affected by the same particle event.

*Verify the particle event by comparing it with the events found at nearby pixels.*

```
PROC amdmsVerifyPE(candidate pixel)
  IF no nearby pixel is marked as a candidate pixel THEN
    remove this candidate pixel;
    RETURN;
  ENDIF
  IF the interval of a nearby candidate pixel and this pixel has no common subset THEN
    remove this candidate pixel;
    RETURN;
  ENDIF
  define the current candidate pixel and the nearby pixel as a common particle event;
ENDPROC
```

If particle events are found, the mean and variance of the affected pixels are recalculated by ignoring the data showing the particle event and afterglow. A particle event map contains, for each pixel, the first and last image number which defines an interval of images where a pixel is influenced by a particle event. If a pixel shows no such effect, both values are -1. Figure B.1.4 shows an image where all found particle events of one series of dark images are shown.

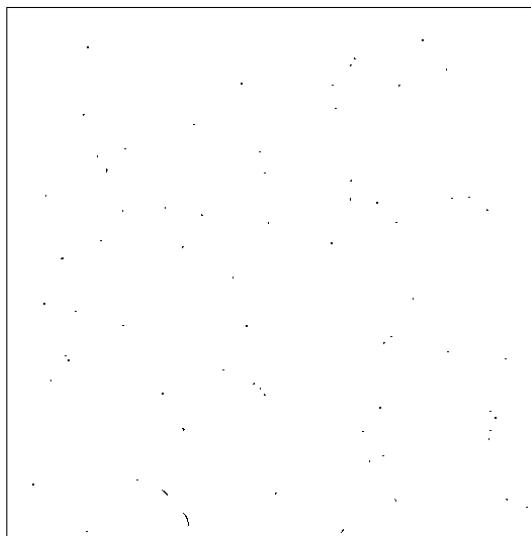


Figure B.1.4: Particle event map for a series of 470 cold dark images with 69 particle events.

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### B.1.4 Electronic Bias

In the left panel of Figure B.1.1, the effects labeled as *Damped Oscillation* and *Electronic Bias* are effects which can be extracted from a series of cold dark images. The result is an electronic bias map (see Figure B.1.5), which can be used to compensate flatfield images or science images for both effects if the setup (subwindow geometry and exposure time) is equal.

The calculation of the electronic bias uses the pixel statistics (see Appendix B.1.5) calculated from a series of cold dark images. The first step extracts the vertical ramp by calculating the mean intensity of a pixel row, ignoring outliers. This ramp is then subtracted from the pixel statistics. In the second step, the damped oscillation is calculated as the mean intensity of a pixel column, ignoring outliers. These offsets are subtracted from the pixel statistics too. The results are mean intensities where the electronic bias has been removed.

```

Calculate a map containing the damped oscillation and the
electronic bias (vertical ramp) from a series of dark images.
PROC amdmsCalculateElectronicBiasQ1()
    allocate memory for the electronic bias map and initialize it with 0.0;
    // extract the vertical ramp from the pixel statistics
    FOR EACH pixel row DO
        calculate the average intensity for this row using all pixels;
        set the lower and upper limit using the average intensity;
        FOR EACH requested number of iterations DO
            calculate a new average intensity for the current row ignoring pixels
            which have a value below the lower limit or above the upper limit;
            recalculate both limits using the new average intensity;
        ENDFOR
        use the last average intensity as the electronic bias for this pixel row;
        subtract this bias from the pixel statistics of this row;
    ENDFOR
    // extract the damped oscillation from the pixel statistics
    FOR EACH pixel column DO
        calculate the average intensity for this column using all pixels;
        set the lower and upper limit using the average intensity;
        FOR EACH requested number of iterations DO
            calculate a new average intensity for the current column ignoring pixels
            which have a value below the lower limit or above the upper limit;
            recalculate both limits using the new average intensity;
        ENDFOR
        use the last average intensity as the electronic bias for this pixel column;
        subtract this bias from the pixel statistics of this column;
    ENDFOR
ENDPROC

```

The implementation of this algorithm in the *amdms* library ensures that at least half of the pixels in a row or column are used to calculate an average intensity. Figure B.1.5 shows an electronic bias map calculated from a series of cold dark images. In this Figure the damped oscillation on the left side and the electronic bias as a vertical ramp are clearly visible.

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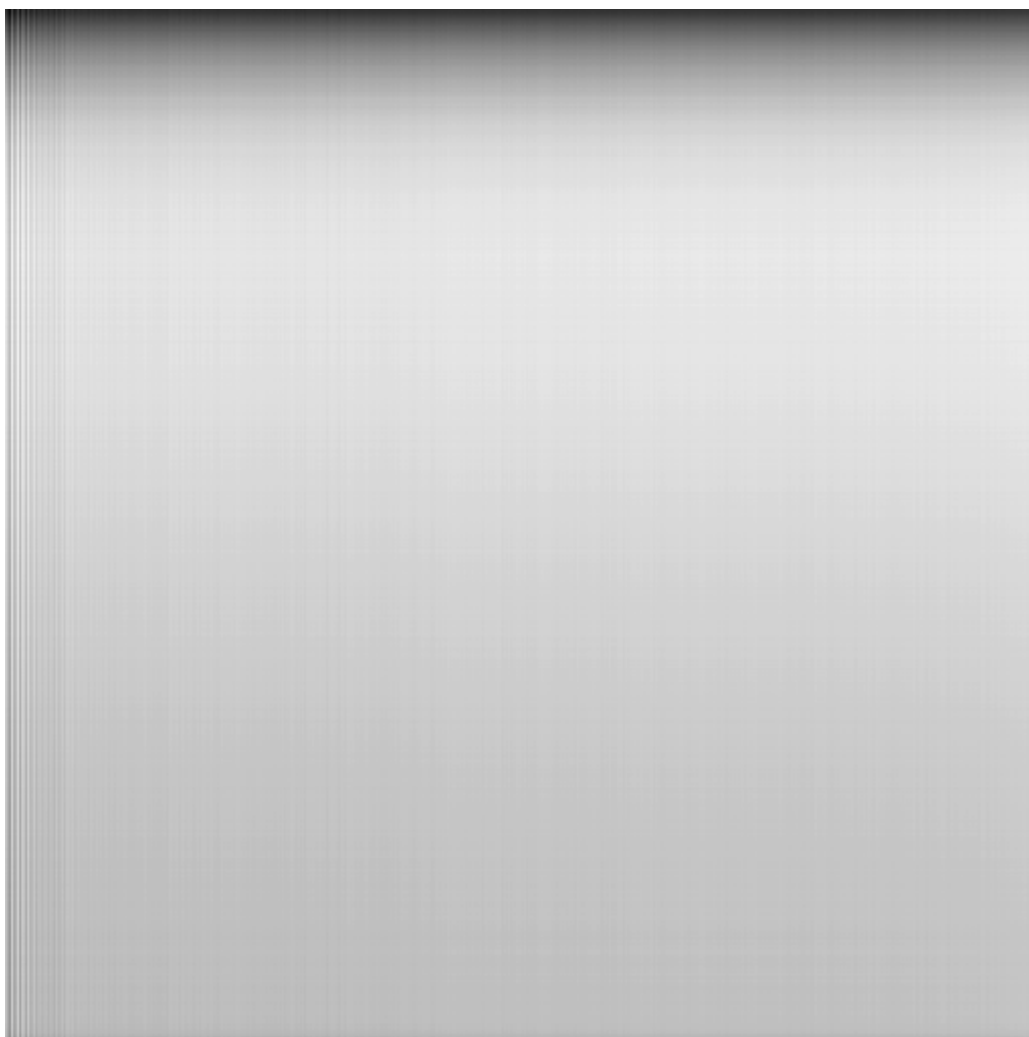


Figure B.1.5: Electronic bias map from a series of dark images with an exposure time of 4.5s.

### B.1.5 Pixel Statistics, Pixel Bias, and Photon Noise

The basis for the calculation of the dark current map (see Appendix [B.1.6](#)), the bad pixel map (see Appendix [B.1.7](#)), and the flatfield map (see Appendix [B.1.8](#)) are the pixel statistics and two derived maps: the pixel bias map and the photon noise map. From each series of cold dark images and flatfield images, the average intensity and temporal variance of each pixel is calculated. These values are calculated by ignoring particle events and subtracting the electronic bias. In Figure [B.1.6](#) the pixel statistics for a series of cold dark images are shown. On the left side, the average intensity shows no electronic bias map, which is obvious if it is compared with a typical cold dark image (see left part of Figure [B.1.1](#)) and the corresponding electronic bias map (see Figure [B.1.5](#)). The temporal variance on the right side of Figure [B.1.6](#) shows no sign of particle events. This indicates that almost all particle events were found and ignored during the calculation.

The pixel bias map used to compensate for a different “pixel offset” for each pixel is equal to the average mean intensity from the pixel statistics map. The photon noise map contains the relation between the measured

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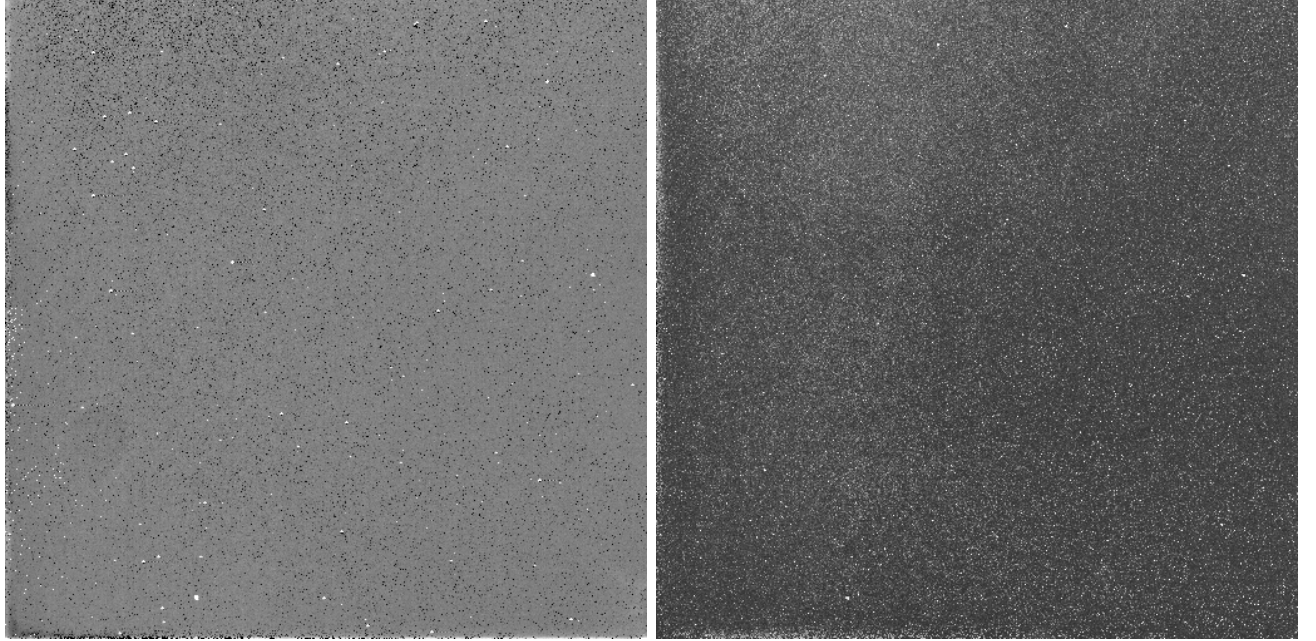


Figure B.1.6: Pixel statistics for a series of cold dark images: **left**: the average intensity for each pixel calculated from a series of 100 cold dark images. The linear scaled image shows values between  $-10DU$  and  $+10DU$ ; **right**: the temporal variance for each pixel is shown in a linear scaled image with 0 and  $+30DU^2$  as limits.

temporal variance and the expected photon noise for each pixel and each series of flatfield images:

$$PN_i = \sqrt{cf \frac{v_i}{m_i}}$$

where  $PN_i$  is the photon noise value of a pixel in the photon noise map,  $cf$  is the conversion factor of  $4.18 \frac{e^-}{DU}$ ,  $v_i$  is the temporal variance, and  $m_i$  is the average intensity from the  $i^{th}$  pixel. In Figure B.1.8 a photon noise map is shown.

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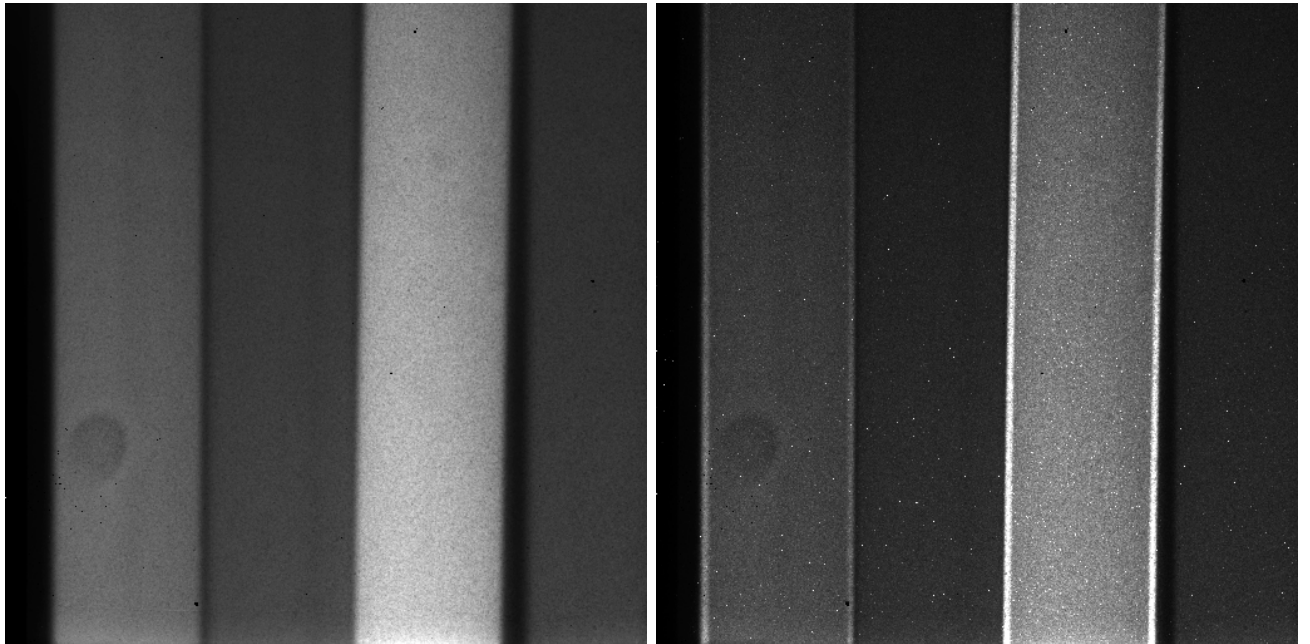


Figure B.1.7: Pixel statistics for a series of flatfield images: **left**: the average intensity for each pixel calculated from a series of 100 flatfield images. The linear scaled image shows values between  $0DU$  and  $+9000DU$ ; **right**: the temporal variance for each pixel is shown in a linear scaled image with 0 and  $+3000DU^2$  as limits.

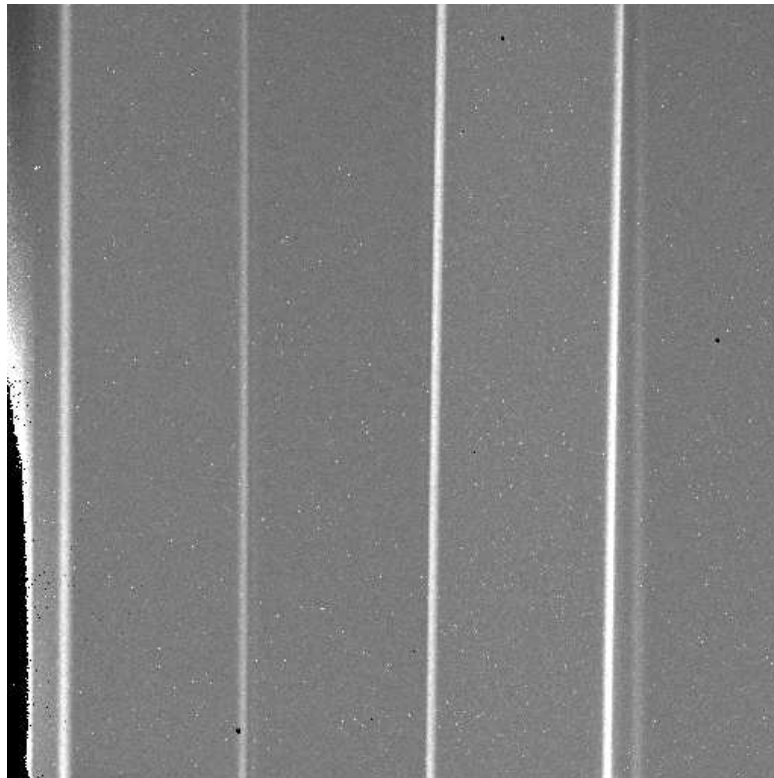


Figure B.1.8: Photon noise map. The image has a linear scale with the limits 0.0 and 2.0.



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### B.1.6 Dark Current

In the typical cold dark image on the left side of Figure B.1.1, some white (hot) and dark pixels can be seen. These pixels do not have a different offset than the other pixels, but the reason for this effect is the following:

When a pixel is reset, a certain number of electrons (about 100 000 - 120 000) are injected into the capacitor of a pixel. If photons are collected by a pixel, electrons are removed from the pixel capacitor. The measured intensity is equal to the difference between those two states. That means if a pixel shows a large value even without light, the capacitor is not perfect; some electrons are lost during the exposure time. The dark pixels have negative values, which means they collect electrons lost by nearby pixel capacitors. This so-called dark current shows up as white and dark pixels in cold dark images. The dark current map tries to quantify this effect.

The dark current map consists of an offset, slope, and fit quality ( $\chi^2$ ) for each pixel. The offset and slope define a straight line where the units are  $[DU]$  and  $[DU/s]$ . During the generation of the bad pixel map (see Appendix B.1.7), upper and lower limits for the slope and upper limits for  $\chi^2$  are used to detect pixels with an unusually high dark current or with a nonlinear dark current.

The input data for the dark current map is a set of pixel statistics maps from the series of cold dark images. Then, a straight line is fitted through the mean intensities for each pixel. The offset, slope, and fit quality are stored in the dark current map. The left panel of Figure B.1.9 shows the offset, the panel in the middle the slope, and the right panel the fit quality.

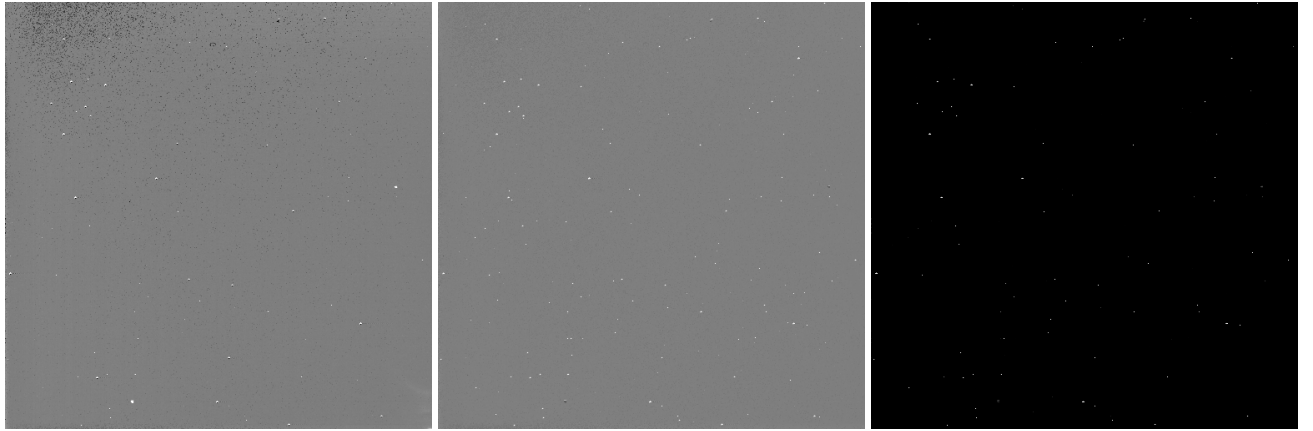


Figure B.1.9: Dark current map for the AMBER detector: **left**: the dark current map contains the offset of the fitted straight line. The image has a linear scale where the lower and upper limits are  $-75e^-$  and  $75e^-$ ; **middle**: the slope of the straight line is shown in this linear scaled image. The lower and upper limits are  $-75e^-/s$  and  $75e^-/s$ , which are the limits used for the bad pixel map generation; **right**: the fit quality ( $\chi^2$ ) is shown in this linear scaled image. The limits are 0.0 and 5.0, which are used for the bad pixel map generation.

### B.1.7 Bad Pixel Map

The pipeline step which generates a bad pixel map uses all intermediate data described in the previous sections. The parameters used for the AMBER detector are shown in table B.1.0.

1. The first step uses the variance values from all pixel statistics maps of all series of cold dark images.

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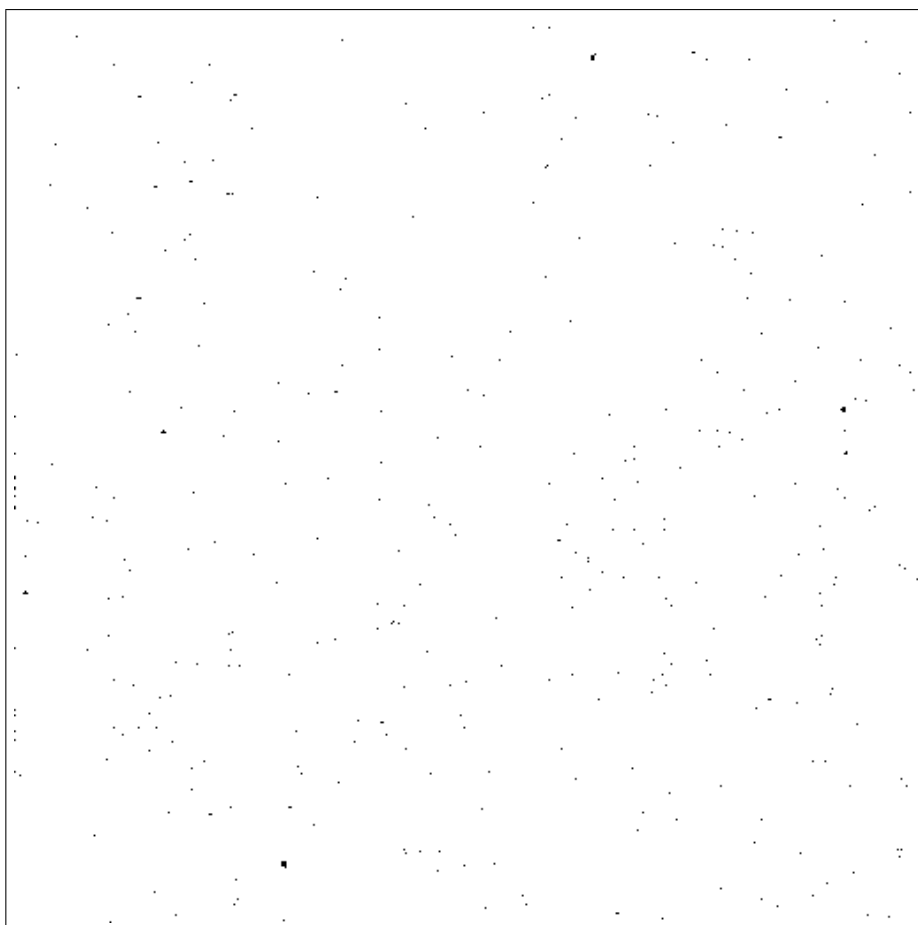


Figure B.1.10: Badpixel map

Pixels which have a variance lower than the minimum value (so-called “dead pixels”) are marked as bad pixels. Pixels which have a variance higher than the maximum value are noisier than a normal pixel and also marked as bad pixels.

2. The second step uses the same criteria for the variance, but this time uses values from all pixel statistics of all series of flatfield images. These images have a shielded area where the conditions are similar to cold dark images and, therefore, the same limits are used for pixels in this area. The illuminated part of the flatfield images is ignored in this step.
3. The third step uses the photon noise values in the photon noise maps generated from all series of flatfield images. If the photon noise of a pixel is less than the minimum value or greater than a maximum value, this pixel is marked as a bad pixel.
4. The fourth step uses the slope value in the dark current map. If a pixel has a slope which is less than the minimum or greater than a maximum value, this pixel is marked as a bad pixel.
5. The fifth step uses the  $\chi^2$  value in the dark current map. If the fit quality is worse than a certain maximum value, this pixel is marked as a bad pixel.

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- The last step uses the average intensity of a pixel compared to the local average. This local value is computed by using all pixels in a local array of pixels which covers 11 times 11 pixels, but the inner part of 3 times 3 pixels is ignored.

Table B.1.0: Parameters for the bad pixel map generation

Step	Criteria	Min value	Reference value	Maximum value
1	Noise in the cold dark images	$0.23 \equiv 2.0e^-$	$6.93 \equiv 11.0e^-$	$321.94 \equiv 75.0e^-$
2	Noise in the shielded area in the flat-field images	$0.23 \equiv 2.0e^-$	$6.93 \equiv 11.0e^-$	$321.94 \equiv 75.0e^-$
3	Photon noise inside vertical stripes	0.5	1.0	2.25
4	Slope in the dark current map dark	$-17.94 \equiv -75.0e^-/s$	$0.0 \equiv 0.0e^-/s$	$17.94 \equiv 75.0e^-/s$
5	$\chi^2$ in the dark current map		0.0	5.0
6	Local average intensity in the flat-field images	$-5.0\sigma$	$0.0\sigma$	$5.0\sigma$

In Figure B.1.10 a bad pixel map is shown which was calculated using the images taken during commissioning 2, 22.10.2004 at Paranal. Except for a few clusters, all bad pixels are isolated and do not interfere with the science data taken in the four vertical stripes (see right part of Figure B.1.1).

### B.1.8 Flatfield Map

A flatfield map for the AMBER detector is calculated by using a set of pixel statistic maps from several series of flatfield images (see left side of Figure B.1.7). For each pixel, a straight line is fitted through the data values, and the normalized slope is used for the flatfield map. A closer look at a typical flatfield image (see right side of figure B.1.1) or a pixel statistics map (see left side of Figure B.1.7) shows that the illumination of the AMBER detector is affected by at least the following effects:

- Only four vertical stripes are illuminated on the detector and the illumination level is different between the four stripes.
- The illumination shows a ramp in vertical direction.
- The illumination shows a horizontal profile, with ramps on both sides of a vertical stripe.

Because of these effects, a normal calculation of the flatfield map is not possible since only a detector flatfield and not an instrument flatfield is required. The effects mentioned above are taken into account by:

- Treating each vertical stripe separately.
- Compensating for the vertical ramp and horizontal profile by using a simple model of the light distribution.

The algorithm used to neutralize the ramp and profile can be described as follows:



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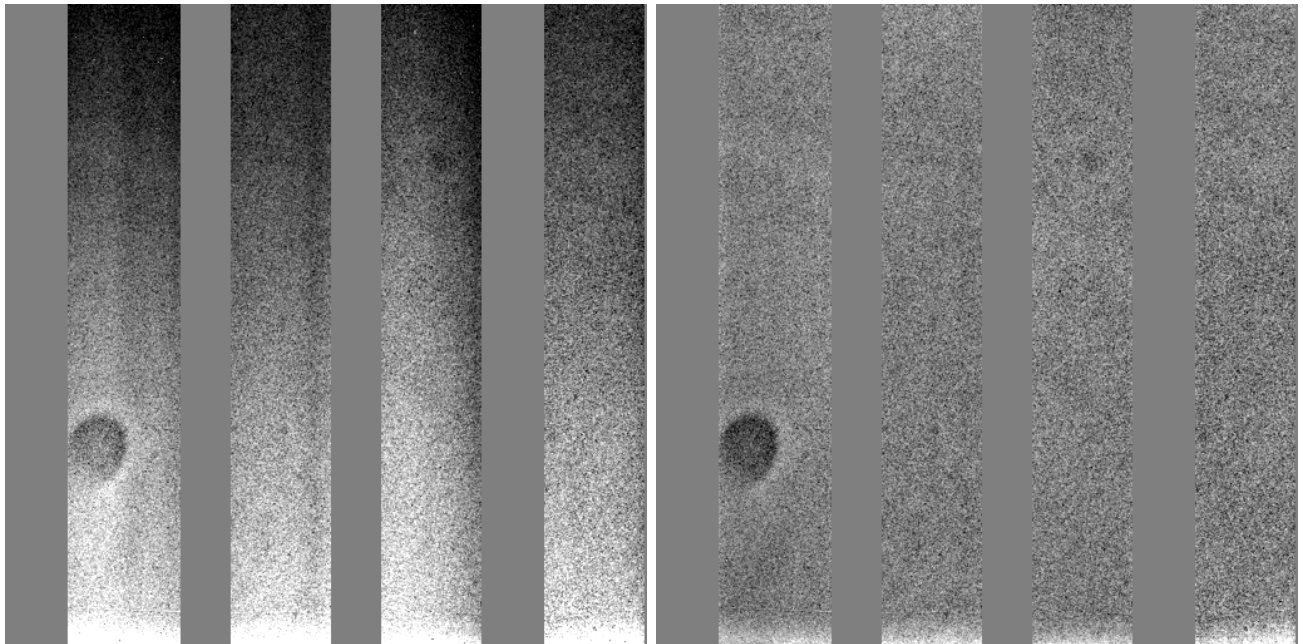


Figure B.1.11: Flatfield map for the AMBER detector: **Left:** the image shows a flatfield map without compensation; **Right:** the image shows a flatfield map with compensation and, therefore, represents only the gain variations of the AMBER detector pixels. Both images have a linear scale with 0.7 and 1.3 as limits.

```

Compensate for the vertical ramp and horizontal profile.
PROC amdmsCleanUpFlatfieldSmooth()
  // calculate a horizontal profile in the lower and upper side of the detector
  FOR EACH pixel column  $i$  DO
    calculate the average intensity for 40 pixels at rows 80 - 120
    and use this value as part of the lower profile  $LP_i$ ;
    calculate the average intensity for 40 pixels at rows 392 - 432
    and use this value as part of the upper profile  $UP_i$ ;
  ENDFOR
  // calculate smoothened profiles (see amdmsSmoothDataByFiniteDiff1)
  smooth the lower profile by using finite differences;
  smooth the upper profile by using finite differences;
  calculate a center profile as average of the lower and upper profile  $CP_i$ ;
  // compensate for the vertical ramp
  FOR EACH pixel column  $i$  DO
    calculate the slope of a straight line as  $a = (UP_i - LP_i)/312$ ;
    FOR EACH pixel row  $j$  DO
      calculate a compensation factor  $f = CP_i / (LP_i + a(j - 100))$ ;
      calculate a new pixel mean as  $m = m \times f$  and a new pixel variance as  $v = v \times f \times f$ ;
    ENDFOR
  ENDFOR
  // compensate for the profile
  FOR EACH vertical stripe  $k$  DO
    calculate the average  $m$  of  $CP_i$  for all pixel columns inside stripe  $k$ ;
    FOR EACH pixel column  $i$  in the current stripe DO
      calculate a compensation factor  $f = m / CP_i$ ;
      calculate new mean and variance values for the pixel column  $i$ ;
    ENDFOR
  ENDFOR
ENDPROC

```

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Figure B.1.11 shows two flatfield maps; one where the vertical ramp and horizontal profile are compensated for, and one without compensation. The gray areas in both images are those areas on the detector without enough light to calculate a useful flatfield value.

### B.1.9 Flat field correction

The flat field correction merely consists of dividing the frame to be corrected by a given master lamp flat field frame produced by the recipe *amber\_detector*

It is currently under discussion if the flat field is implicit with the p2vm correction.

## B.2 AMBER-specific Algorithms

For a detailed description of AMBER-specific algorithms please refer to the AMBER data reduction plan, VLT-PLA-AMB-15830-6004.

The following description is a very minute introduction taken from the document before mentioned.

### B.2.1 P2VM calculation

The fringe pattern produced on the camera by any two pair of entrance beams, in any of the (up to 3) spectral bands imaged, must be calibrated beforehand, since it depends strongly on the current instrument configuration, especially the position of beams wrt. the pupil masks, and the position of the dispersing elements. Calibrating this fringe pattern is called calibrating the Pixel-to-Visibility Matrix (the P2VM). The AMBER OS will prevent the acquisition of science data when the corresponding P2VM has not been calibrated.

A P2VM calibration is performed by obtaining one frame with all shutters closed to get a sky-type frame, then by opening in turn only one shutter to get the shape of the illumination in the interferometric channel due to one fiber (the so-called vik), then by opening in turn pairs of shutters to retrieve the interference fringe pattern for each pair of telescope, with and without a phase shift of a known value.

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0. The visibility of the artificial source (lamp) in the CAU is supposed to be fixed, calibrated and noted V0.

1. CAU Lamp: ON
2. CAU mirror on CAU position.
3. Shutter 1 Close, 2 Close, 3 Close
4. take image File: AMBER 3TSTD CAL 0001.fits
5. Shutter 1 Open, 2 Close, 3 Close
6. take image File: AMBER 3TSTD CAL 0002.fits
7. Shutter 1 Close, 2 Open, 3 Close
8. take image File: AMBER 3TSTD CAL 0003.fits
9. Phase Plate position Off (INS OPTI4 NAME = DEL NO )
10. Shutter 1 Open, 2 Open, 3 Close
11. take image File: AMBER 3TSTD CAL 0004.fits
12. Phase Plate position On (INS OPTI4 NAME = DEL1 2 )
13. Shutter 1 Open, 2 Open, 3 Close
14. take image File: AMBER 3TSTD CAL 0005.fits
15. Shutter 1 Close, 2 Close, 3 Open
16. take image File: AMBER 3TSTD CAL 0006.fits
17. Phase Plate position Off (INS OPTI4 NAME = DEL NO )
18. Shutter 1 Close, 2 Open, 3 Open
19. take image File: AMBER 3TSTD CAL 0007.fits
20. Phase Plate position On (INS OPTI4 NAME = DEL12 3 )
21. Shutter 1 Close, 2 Open, 3 Open
22. take image File: AMBER 3TSTD CAL 0008.fits
23. Phase Plate position Off (INS OPTI4 NAME = DEL NO )
24. Shutter 1 Open, 2 Close, 3 Open
25. take image File: AMBER 3TSTD CAL 0009.fits
26. Phase Plate position On (INS OPTI4 NAME = DEL12 3 )
27. Shutter 1 Open, 2 Close, 3 Open
28. take image File: AMBER 3TSTD CAL 0010.fits

Note that the 5 first steps are needed for a 2 Telescope P2VM. Those calibration frames are processed with amdlib routines to produce a P2V Matrix used for all following visibility extraction, until the Instrument Setup changes and a new P2VM is needed.

Of the previously described calibration frames, the first is a sky-like measurement, without input light. This is done in order to subtract the uncorrelated light sky due to the thermal emission of the fibers, if any. The next three frames are exposures with only one input beam. This allows one to compute the vk coefficients in the equations described before, by dividing the interferometric channel by the measured photometric flux, pixel by pixel and for every input beam. The other 6 frames completely determine the calibration of the instrument. In these frames, two input beams at a time are combined. Per baseline two exposures are made. In one of this couple of frames, an additional phase shift is inserted into one of the beams.

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