E U R O P E A N S O U T H E R N O B S E R V A T O R Y

Organisation Européenne pour des Recherches Astronomiques dans l'Hémisphère Austral
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VERY LARGE TELESCOPE
NaCo
User Manual

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CHANGE RECORD

ISSUE	DATE	SECTIONS AFFECTED	REASON/INITIATION DOCUMENTS/REMARKS
First issue	31/7/2001	all	New
82.1	26/2/2008	all	New revisited version! Changed list of authors. Porting to doc/pdf Introduction of cube, SAM and pupil tracking modes.
82.2	27/7/08	All	Corrected some errors related to the use of the Return to Origin? Flag in some templates. Eliminated the Add. Velocity parameters.. Correction of typos
83.1	03/08/08	2	Modified for p83
		5.6	Updated, added faint targets with SAM
		5.10	Added section on data format
		6.8	Updated
		10	Added DPR keywords table.
		All	Improved figures, reformatting.
83.2	06/10/08	All	Typos Addenda for the new modes (sam, cube, data format, pupil tracking)
83.3	09/10/08	All	New info on new modes after change-over to P82.

TABLE OF CONTENTS

LIST OF TABLES

1 SCOPE

This is the Naos-Conica (hereafter, NaCo) User's Manual. It can be used as a reference for users interested in preparing observing proposal with NaCo. This document has been completely revised and partly rewritten in 2008, using the latest available version, authored by N. Ageorges and C. Lidman.

1.1 List of Abbreviations & Acronyms

This document employs several abbreviations and acronyms to refer concisely to an item, after it has been introduced. The following list is aimed to help the reader in recalling the extended meaning of each short expression:

Acronym	Meaning
4QPM	Four Quadrant Phase Mask
4QPM_H	Four Quadrant Phase Mask optimized for H band
4QPM_K	Four Quadrant Phase Mask optimized for K band
AO	Adaptive Optics
ATP	Acceptance Test Plan
ATR	Acceptance Test Report
CCS	Central Control Software
CONICA	High Resolution IR Camera and Spectrometer
CPU	Central Processing Unit
DCR	Double_RdRstRd
DCS	Detector Control Software
DFS	Data Flow System
DIT	Detector Integration Time
DM	Deformable Mirror
DPR	Data Product
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FLI	Fractional Lunar Illumination
FNS	FowlerNSampling
FoV	Field of View
FP	Fabry-Perot
FS	Field Selector
FW	Full well
FWHM	Full-Width at Half Maximum
GUI	Graphical User Interface
HB	HighBackground
HD	HighDynamic
HS	HighSensitivity
HWD	HighWellDepth
HW	Hardware
HWP	Half-Wave Plate
IB	Intermediate band
ICS	Instrument Control Software
INS	Instrumentation Software Package
I/O	input/output
IR	Infra-red
IRACE	Infra-red Array Control Electronics
ISF	Instrument Summary File
IWS	Instrument Workstation
JNPS	Java NaCo Preparation Software

LAN	Local Area Network
LCC	LCU Common Software
LCU	Local Control Unit
LGS, LGSF	Laser Guide Star, Laser Guide Star Facility
LN2	Liquid Nitrogen
LW	Long Wavelength
M2	Secondary Mirror
mas	Milli-arcsec
MS	Maintenance Software
MSCO	Residual (Modal) Slope Covariance matrix
MVCO	Modla Voltages Covariance matrix
MTF	Modulation Transfer Function
N/A	Not Applicable
NAOS	Nasmyth Adaptive Optics System
NaCo	NAOS-CONICA
NB	Narrow Band
ND	Neutral Density
NDIT	Number of Detector Integration Time
NGS	Natural Guide Source
OB	Observation Block
PAE	Preliminary Acceptance Europe
P2PP	Phase 2 Proposal Preparation
PS	Preparation Software
PSO	Paranal Science Operations
PSF	Point-Spread Function
RAM	Random Access Memory
RON	Read Out Noise
RTAP	Real-Time Application Platform
RTC	Real-Time Computer
RTD	Real Time Display
SAM	Sparse Aperture interferometric Mask
SAMPol	Sparse Aperture interferometric Mask + Polarimetry
SDI	Simultaneous Differential Imaging
SDI+	Simultaneous Differential Imager
SDI+4	Coronagraphy with 4QPM and Simultaneous Differential Imager
SM	Service Mode
SR	Strehl Ratio
SW	Short Wavelength
TBC	To Be Clarified
TBD	To Be Defined
TCS	Telescope Control Software
TIM	Time Interface Module
TRS	Time Reference System
TSF	Template Signature File
TTM	Tip-Tilt Mirror
TTS	Tip-Tilt Source
VLT	Very Large Telescope
VM	Visitor Mode
WF	Wavefront
WFS	Wavefront Sensor
WS	Workstation
ZNVA	Zernike Noise VAriance

2 INTRODUCTION

The Nasmyth Adaptive Optics System (NAOS) and the High—Resolution Near IR Camera (CONICA) are installed at the Nasmyth B focus of UT4. NaCo provides multimode, adaptive optics corrected observations in the range 1-5 μm.

NAOS (Section 4) is an Adaptive Optics (AO) system (Section 4.1) that is designed to work with natural guide sources (NGS, point-like or extended objects) with either a visible or an IR wavefront sensors. It can also use a Laser Guide Star (LGS) Beacon and a natural Tip-Tilt source (TTS) to provide AO correction with somewhat degraded performance with respect to NGS.

CONICA (Section 5) is an Infra-Red (IR) (1 - 5 μm) imager and spectrograph fed by NAOS. It is capable of imaging, long slit spectroscopy, simultaneous differential imaging (SDI), coronagraphy, polarimetry and sparse aperture interferometry, with several different plate scales, filters and options (e.g. cube mode for "lucky-imaging", pupil tracking for imaging, coronagraphy and SDI). The modes offered for P83 are listed in Table 2-1

NaCo can be used in Service (SM) or Visitor Mode (VM). The Observatory provides daily calibrations, as the NaCo Calibration Plan. Pipelines for quick look data reduction are available for some modes of the instrument.

Table 2-1: Main modes and parameters of NaCo.

Adaptive Optics Performance	40% Strehl ratio in K under good atmospheric conditions and with a reference object of V=10 mag or K=6 mag
Imaging	Broad- and narrow- band filters in the 1-5 μm region with 14"–56" fields of view and 13–54 mas pixel scales Simultaneous Differential Imaging (SDI+).
Coronagraphy	Occulting masks of various diameters + 4 quadrant phase masks: 4QPM_H, 4QPM_K (VM only). Simultaneous Differential Imaging plus Coronagraphy (SDI+ & 4QPM_H, VM only)
Spectroscopy	Long slit and slitless spectroscopy with 4 grisms of resolving power 400–1400 and prism spectroscopy of resolving power variable from 40 to 250 over the covered spectral range. Spectroscopy is only offered in VM.
Polarimetry	Imaging with a Wollaston prism.
SAM	Sparse Aperture Interferometry with 4 different masks. SAM is only offered in VM.
SAMPol	SAM with polarimetry, offered in VM.

This manual is organized as follows:

- Section 3.: a summary of AO techniques and IR observations.
- Section 4.: description of NAOS
- Section 5: description of CONICA
- Section 6: operations with NaCo.
- Section 7: acquisition and observations templates manual.
- Section 8: filters transmission curves.
- Section 9: the Preparation Software (PS) user manual.
- Section 10: Appendix – DPR keywords for NaCo.

2.1 Additional resources

NaCo Web Pages	http://www.eso.org/instruments/naco
NaCo Online Documentation	http://www.eso.org/instruments/naco/doc/
NaCo News	http://www.eso.org/instruments/naco/news.html
NaCo contributed library	http://www.eso.org/instruments/naco/tools/library.html
NaCo Call for Proposal	http://www.eso.org/sci/observing/proposals/
NAOS Preparation Software	http://www.eso.org/observing/p2pp/OSS/NAOSPS/
Exposure Time Calculator	http://www.eso.org/observing/etc/
Catalogues for adaptive optics reference objects	Optical sources: ESO GSC2 (skycat): http://archive.eso.org/skycat/ GSC2 at STScI http://www-gsss.stsci.edu/ Infrared Sources (VIZIER Catalogue): http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=2MASS
Phase 2 Proposal Preparation	http://www.eso.org/observing/p2pp/NaCo/NaCo-P2PP.html
User Support Department	http://www.eso.org/org/dmd/usg/
NaCo Quality Control	http://www.eso.org/observing/dfo/quality/index_naco.html

For any question regarding NaCo Service Mode operations, the point of contact is the User Support Department (usd-help@eso.org) in Garching. Users with approved Visitor Mode programs can contact naco@eso.org.

2.2 Current version of the manual

This is version 83.3 of the NaCo User Manual, applicable for phase I preparation of P83 and Phase II of P82. Since NaCo is being constantly improved and modes are refined (especially the new ones), it is advisable to **check the NaCo web page for possible updates to this manual and for recent news**.

2.3 Changes for P83

The following changes will be implemented for P83:

- **SAMPol – Tentatively offered**, pending commissioning: sparse aperture mask interferometry (SAM) can be combined with polarimetry. The simultaneous use of the Wollaston_00 together with the SAM masks presents a unique opportunity to examine systems where there may be polarization signals at very high spatial resolutions. SAMPol is similar to SAM and uses pupil tracking and cube modes. SAMPol is only offered in VM.
- **Fabry Perot** will not be offered. Users are encouraged to consider SINFONI as an alternative.
- **Spectroscopy** will only be offered in VM. This applies to both prism and grism spectroscopy.
- **Wire Grid Polarimetry** will be discontinued. Users can opt for the Wollaston_00 in combination with the retarder plate.
- **Special calibrations:** all observations requesting special calibrations will be moved to VM. Exceptions to this rule will be considered on a case-by-case basis during technical feasibility.

3 OBSERVING WITH ADAPTIVE OPTICS IN THE INFRARED

3.1 Atmospheric turbulence

The VLT (Very Large Telescope) has a diffraction-limited resolution of $\lambda/D = 0.057''$ at λ=2.2 μm. But the resolution is severely limited by atmospheric turbulence to $\lambda/r_0 \sim 0.7''$, where r_0 is the Fried parameter. The Fried parameter is directly linked to the strength of the turbulence and it depends on the wavelength as $\lambda^{6/5}$.

For average observing conditions, r_0 is typically 60 cm at 2.2 μm. The correlation time of the turbulence, τ_0, is related to r_0 and the speed at which the turbulent air travels. For a wind speed of 10 m/s the correlation time is of the order of 60 ms at 2.2 μm. Both τ_0 and r_0 are critical parameters. The larger they are the more stable the atmosphere is and the better the performance of NAOS will be. Atmospheric conditions are better suited to AO observations during the summer months in Paranal, with larger τ_0 and r_0.

3.2 Adaptive optics

A powerful technique in overcoming the degrading effects of atmospheric turbulence is real-time compensation of the deformation of the wavefront (WF) by adaptive optics (AO, Figure 3-1). The wavefront sensor (WFS) measures WF distortions and these measurements are processed by a real-time computer (RTC). The RTC controls a deformable mirror (DM) and corrects the WF distortions. The DM is a continuous thin plate mirror mounted on a set of piezoelectric actuators that push and pull on the back of the mirror. Because of the significant reduction in the WF error by AO correction, it is possible to record images with exposure times that are significantly longer than the turbulence correlation time. The WF error directly determines the quality of the formed image.

One of the main parameters characterizing this image quality is the Strehl ratio (SR), which basically corresponds to the amount of light contained in the diffraction-limited core relative to the total flux.

An AO system is a servo-loop system working in closed loop. The DM flattens the incoming WF and the WFS measures the residual WF error. The WFS in NAOS uses a Shack-Hartmann screen. It consists of a lenslet array that samples the incoming WF in a pupil plane. Each lenslet forms an image of the object and the displacement of the image gives an estimate of the WF slope at that lenslet. A good feature of this WFS is that it works with white light, extended sources and very faint stars.

The performance of an AO system is directly related to the number of lenslets in the lenslet array, the number of actuators behind the DM, and the rate at which WF errors can be measured, processed and corrected (the server-loop bandwidth). The performance of an AO system is also directly linked to the observing conditions. The most important parameters are the seeing (or more explicitly r_0 and t_0), the brightness of the reference source used for WFS and the distance between the reference source and the object of interest.

In case of good conditions and a bright, nearby reference source, the correction is good and the resulting point spread function (PSF) is very close to the diffraction limit.

A good correction in the K-band typically corresponds to a SR larger than 30%.

At shorter wavelengths (particularly in the J-band) or in the case of poor conditions or a faint, distant reference source, the correction is only partial - the Strehl ratio may only be a few percent.

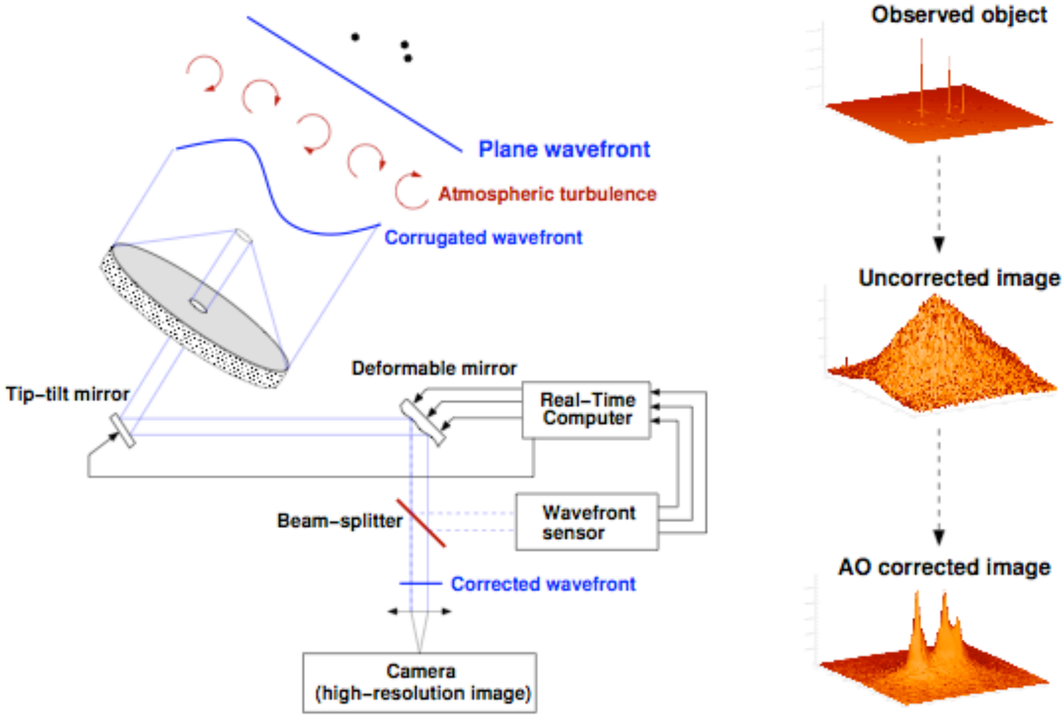


Figure 3-1: Principle of Adaptive Optics

3.3 Infrared Observations with an AO system

Observing in the IR with an AO system is, in broad terms, very similar to observing with other IR instruments. One has to deal with high and variable backgrounds and modest detector cosmetics. In general, the IR background, particularly at longer wavelengths, is higher for an IR instrument with an AO system, because of the additional optics in an AO system. Additionally, the classical chop and nod technique, which is commonly used for the LW filters in non-AO systems, works less well as the DM introduces background fluctuations that do not cancel perfectly. This does not degrade L-band observations but it may degrade M-band observations. Given the relatively small field of view of CONICA, it is possible to observe in the L-band without having to chop and nod. However, the overheads are relatively large (typically 50-100%) because the sky has to be sampled frequently (at least once a minute), and poor results can be obtained if one does not offset frequently or if the time scale for fluctuations in the L-band background is short. We **strongly** recommend that users limit themselves to the *autojitter* template, if they choose not to use the classical chop and nod technique. Users are free to choose between jittering and the more classical chop and nod style of observations for the Lp, NB_3.74 and NB_4.05 filters. Observations in the M-band can only be done with chopping.

One of the major differences between AO and non-AO systems is the pixel scale. The pixel scale of CONICA can be as fine as 0.013", which is a factor 10 smaller than ISAAC. Hence, it will take ~100 times longer to reach background limiting performance. Additionally, the fields-of-view are smaller, so large scale changes in the sky background are less noticeable in CONICA than in ISAAC. Thus, the typical integration time and the typical amount of time between telescope offsets will be larger for CONICA.

3.4 Transmission and background

The transmission of the Earth's atmosphere in the 1–5 μm region is shown in Figure 3-2. The X, J, H, K, L and M bands correspond to atmospheric windows which are approximately centred at 1, 1.25, 1.65, 2.2, 3.6, and 4.8 μm The absorption is mostly due to water and carbon dioxide and it varies with zenith distance and the amount of water vapour.

As regards observations with NaCo, the sky background can be split into two regions. Below ~2.2 μm the sky background is dominated by OH emission that originates at an altitude of ~80 km. At longer wavelengths the thermal background of the atmosphere and telescope dominate.

3.5 Background subtraction

Subtraction of the background is critical to the success of observing in the IR and special observing techniques have been developed to do it. The techniques depend on the type of observation and on the wavelength region at which one is observing. For imaging observations short ward of 4.2 microns and for regions that are relatively un-crowded (i.e. tens of point sources in 20 square arcsec or moderately extended objects), the standard practice is to resort to the **jitter** technique, and most NaCo imaging templates make use of it. The technique basically consists of taking numerous images of the field (typically 10 or more) with small offsets between the positions. The sky is then estimated from all the observations. The most critical aspect of jittering is that the size of the offsets should be larger than the spatial extent of the object(s) one is observing. For more crowded fields or extended objects (i.e. covering a large fraction of the array), the jittering technique works less well and the sky has to be sampled separately from the object, resulting in a loss of observing efficiency, which can amount to 50% of the time if the sky has to be sampled as frequently as the object. Still, all the `object' positions can be "jittered" between themselves, as well as the `sky' positions. This minimises the effect that poor array cosmetics have on the data. In the case of crowded fields where there is no suitable, nearby sky field, the jittering technique can still give good results as long as the number of offsets is large, i.e. greater than 20. In spectroscopy, the classical technique is to observe point sources or moderately extended sources at two or more positions along the slit, allowing one to integrate continuously on the object. For crowded fields or extended objects, the sky has to be sampled separately from the object. At thermal IR wavelengths (> 3 μm) the background is considerably higher and more variable. In order to avoid saturation, the detector at these wavelengths needs to be read very rapidly which in turn leads to poorer detector cosmetics.

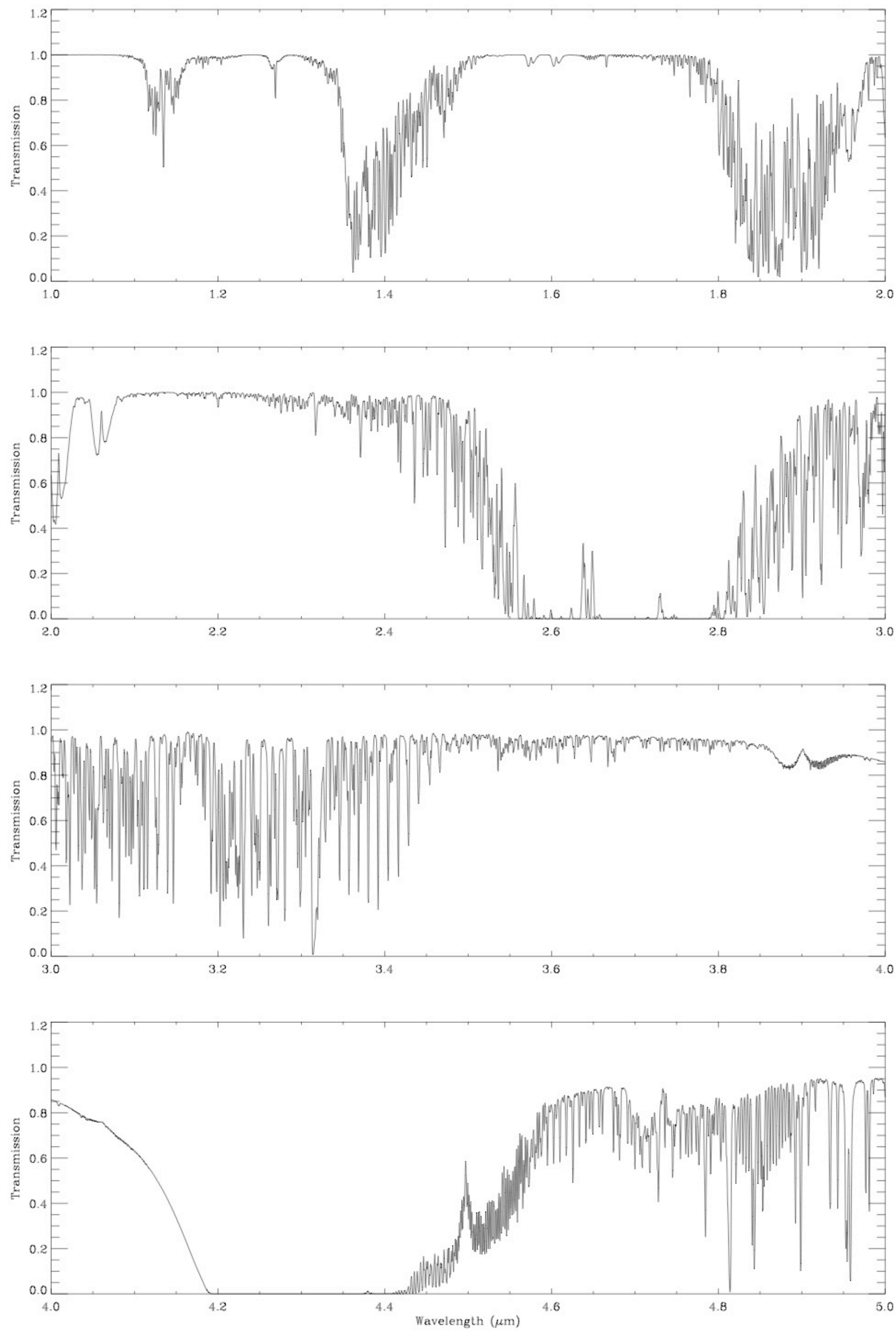


Figure 3-2: Model atmospheric transmission between 1 and 5 μm for a water vapour column density of 1.6 mm and at airmass 1 (Lord 1992, NASA Tech. Mem. 103957).

The standard sky subtraction technique is to use chopping and nodding. Chopping is achieved by synchronizing the readout of the detector with the secondary mirror of the telescope (M2), which alternates (chops) between two positions. If the chopping is fast enough, efficient subtraction of the sky can be achieved by subtracting the images taken at the alternate positions. The result of a chopped image is therefore a background-subtracted image with positive and negative (if within the field of view of the detector) objects. For NaCo, the typical distance between the two positions (the chop throw) is 10" and the chopping frequency is typically around 0.1 Hz. Usually, it is essential to combine chopping with telescope nodding, i.e. offsetting in the opposite direction of the chop, because chopped images usually leave strong residuals on the detector, due to the different optical paths through the telescope. With AO fed systems, there is an added complication. The amplitude of the residuals depends on the strength of the turbulence (stronger turbulence means that the deformable mirror has to work harder) and the residuals on the two sides of the nod are generally different. Consequently, they cannot be perfectly removed. For observations with NaCo it is not necessary to use chopping and nodding for LW imaging, spectroscopic and polarimetric observations if the central wavelength of the filter is less than 4.2 μm, the sky is sampled frequently (i.e. **more** than once per minute) and **if** conditions are clear. But, for coronagraphic observations, where one cannot jitter, and for filters with wavelengths greater than 4.2 μm, efficient subtraction of the sky background will require chopping and nodding.

3.6 Spectroscopy

Spectroscopic observations with an AO system lead to the following effects.

- An increase in the Strehl ratio along the spectrum with increasing wavelengths. Depending on the setting, the Strehl ratio can change by 10%.
- A wavelength shift caused by the change in the Strehl ratio as a function of wavelength. In particular, at shorter wavelengths the FWHM of the PSF of the science object can be smaller than the slit width, which leads to the wavelength shift that depends on the location of the object in the slit.
- A complex line profile. The spectrum is the sum of a diffraction limited core and a halo that is limited by the external seeing. The result is a combination of line profiles in the final spectrum: the line core is at the highest spectral resolution while the wings have a lower spectral resolution since they are defined by the slit width.

Calibrating AO corrected IR spectra is, therefore, more complicated than calibrating IR spectra from a non-AO instrument. The steps are similar in both cases, but the accuracy at which it can be done in AO corrected spectra is likely to be lower. It will be harder to remove telluric lines that come from the Earth's Atmosphere and to do spectro-photometric calibration.

4 NAOS

4.1 Overview

NAOS provides a turbulence-compensated f/15 beam and a 2 arcmin FoV to CONICA. Two off-axis parabolas re-image the telescope pupil on the deformable mirror and the Nasmyth focal plane on the entrance focal plane of CONICA. A schematic sketch of the optical train of NAOS common path is shown in Figure 4-1. The optical trains of the wavefront sensors are not shown in this figure.

The tip-tilt plane mirror (TTM) compensates for the overall WF tip and tilt, which are the largest disturbances generated by the turbulence.

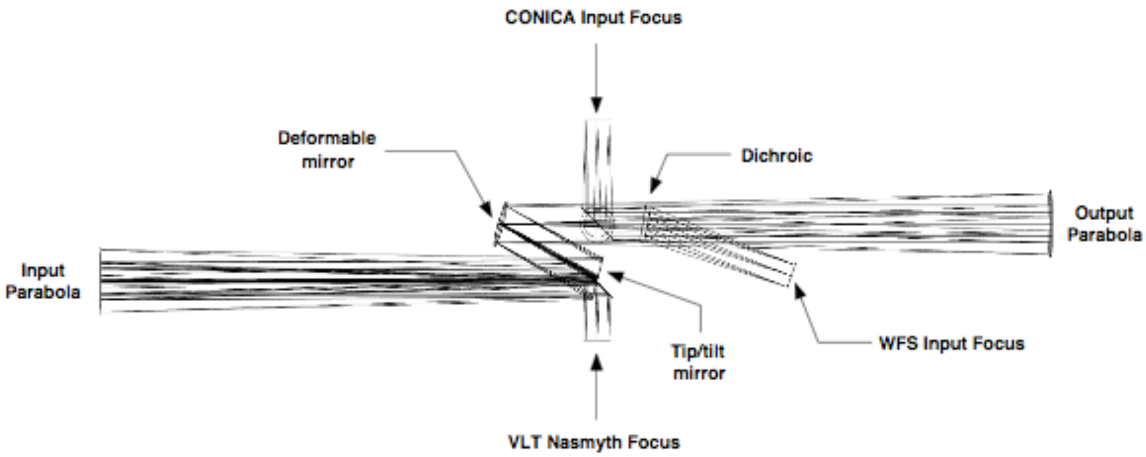


Figure 4-1: A view of the NAOS optical train.

The DM, which contains 185 actuators, compensates for the higher order aberrations including the static aberrations of NAOS and CONICA.

Table 4-1: NaCo dichroics/beamsplitters

Dichroic Name	Reflected light to the WFS	Efficiency	Transmitted light to CONICA	Efficiency	Use
VIS	V,R,I 0.46-0.95 μm	90 %	J,H,K,L,M 1.05-5.0 μm	90%	Near-IR observations with optical WFS
N20C80	V,R,I,J,H,K 0.45-2.55 μm	20 %	V,R,I,J,H,K 0.45-2.55 μm	80 %	WFS and observations in the IR
N90C10	V,R,I,J,H,K 0.45-2.55 μm	90 %	V,R,I,J,H,K 0.45-2.55 μm	10%	WFS and observations in the IR[1]
JHK	I,J,H,K 0.80-2.55 μm	90 %	L,M 2.8-5.5 μm	90%	Thermal-IR observations and near-IR WFS
K	K 1.9-2.55 μm	90%	V,R,I,J,H 0.45-1.8 μm	90%	J, H observations and K band WFS

[1] The N90C10 dichroic can also be used with the visible WFS. In this case, it acts as a neutral density filter.

A dichroic splits the light between CONICA and the WFS channel. Each dichroic is associated with one WFS with the exception of the N90C10. For example, the visual dichroic can only be used with the visual WFS and the other dichroics can only be used with the IR WFS. The conditions under which the dichroics can be used are listed in Table 4-1. Users are invited to study this table carefully. The N90C10 can be used with the visible WFS and serves as a neutral density filter for CONICA.

A field selector (FS) is placed just after the WFS input focus in order to select the reference object for WF sensing. The FS also allows object tracking, pre-calibrated flexure compensation and counter-chopping. It is made up of two parallel tip-tilt mirrors working in closed loop to achieve a very high angular stability.

Two WF sensors are implemented in NAOS: one operating in the visible and one in the near–IR. An off-axis natural guide star (NGS) can be selected anywhere within a 110 arcsec diameter field of view (FoV), facilitating a target-to-reference distance of up to 55 arcsec. NAOS allows WF sensing with faint NGS and extended objects but with lower performance. Observations of very bright objects are possible with the visible WFS using neutral density filters. Note that these neutral density filters are distinct from the neutral density filters of CONICA and are not selectable within the NAOS-PS software or within P2PP. They are linked to the first three available AO-modes (1-1, 1-2 and 1-3).

The two WF sensors are of the Shack-Hartmann type. For the visible WFS, two configurations are available: a 14×14 lenslet array, with 144 valid sub-apertures and a 7×7 lenslet array, with 36 valid sub-apertures. For the IR WFS, three configurations are available: a 14×14 lenslet array, with 144 valid sub-apertures and two 7×7 lenslet arrays, with 36 valid sub-apertures, with different FoVs. Independent of which Shack-Hartmann sensor is being used, all 185 actuators on the DM are used. The FoV, the temporal sampling frequency and the pixel scale of the WFS can also be optimized, providing a good performance over a large magnitude range. Characteristics of both WFS are given in Table 4-2.

Table 4-2: Wavefront sensors characteristics

Characteristics	Visible WFS	Infrared WFS[1]
Wavelength range	0.45 – 1.0 μm	0.8 – 2.5 μm
FoV per lenslet		
14×14	2.32″	5.15″
7×7	4.64″	4.8″ (V0) and 5.5″ (V1)
Magnitude range		
14×14	0-12	4-9
7×7	12-16.7	9-12
Detector	128×128 EEV CCD	1024×1024 Rockwell Hawaii

4.2 NAOS Performance

The level of the AO correction depends on a large number of factors, such as seeing, the speed of the turbulence, the airmass, the brightness and morphology of the reference object, the distance between the reference object and target and instrument performance.

The performance of NAOS is summarised in Table 4-3. The preparation software should be used for more detailed predictions and simulated PSFs.

1 With the N20C80 dichroic. The magnitude ranges with the N90C10 dichroic are approximately 1.5 magnitudes fainter.

Table 4-3: Summary of NaCo Strehl ratios at 2.2 microns for an A0 reference star at an airmass of 1.2. Values are listed for the on-axis case (when the source and the reference are the same) and for a source that is 30″ away from the reference star. The assumed seeing values are 0.8″and 1.2″ (at Zenith at a wavelength of 0.5 mm). These values were derived with the Preparation Software (PS) and are also used in the CONICA Phase I Exposure Time Calculator to estimate signal-to-noise ratios.

V magnitude	Strehl ratios (SR) [%]			
	On-axis (0.8″ seeing)	30″ off-axis (0.8″ seeing)	On-axis (1.2″ seeing)	30″ off-axis (1.2″ seeing)
10.0	47	9	32	1.5
11.5	44	9	12	1.4
13.0	26	7	7	1.3
14.5	17	5	5	1.0
16.0	5	3	1	0.7

Note that a seeing of 0.8″ or better can be obtained on Paranal 50% of the time, while 1.2″ or better can be obtained 80% of the time.

4.3 Anisoplanatism

Anisoplanatism is the field dependence of the PSF. It corresponds to the angular decorrelation of the wavefront coming from two angularly separated stars. This phenomenon affects the quality of the AO correction in the direction of the target when the reference star is not on axis.

4.4 Laser Guide Star Facility (LGSF)

Adaptive Optics Operations are strongly affected by the size of the isoplanatic angle, usually 20" at 2μm, but only 5″ (in diameter) at 0.6μm. Even for observations at 2.2μm, the sky coverage achievable by this technique (equal to the probability of finding a suitable reference star in the isoplanatic patch around the chosen target) is only of the order of 0.5 to 1%. The most promising way to overcome the isoplanatic angle limitation is the use of artificial reference stars, or laser guide stars (LGS). Laser Guide Stars are artificial sources, potentially replacing Natural Guide Stars (NGS) as reference objects for Adaptive Optics (AO) image corrections. The rationale is the much higher sky coverage offered in principle by an LGS, as opposed to the standard NGS approach. Due to the bright (V~11-13) artificial star created near the centre of the field, the probability to achieve a given minimum AO correction on an arbitrary astronomical target, goes e.g. from a meagre 3% with an NGS to 65% with an LGS, for corrected images with at least a 20% K-band Strehl ratio.

Nevertheless, there are still a number of physical limitations with an LGS. The first problem is the focus anisoplanatism, also called the cone effect. Because the artificial star is created at a relatively low altitude, back-scattered light collected by the telescope forms a conical beam, which does not cross exactly the same turbulence-layer areas as the light coming from the distant astronomical source. This leads to a phase estimation error. The effect is roughly equivalent on an 8-m telescope to the phase error experienced with an NGS 10″ away from the astronomical target. However, contrary to the case of NGS-only AO, LGS-based corrections saturate at a relatively low maximum K-band Strehl ratio of 55%, due to the cone effect.

Even more severe is the image motion or tilt determination problem. Because the paths of the light rays are the same on the way up as on the way down, the centroid of the artificial light spot appears to be stationary in the sky, while the apparent position of an astronomical source suffers lateral motions (also known as tip/tilt). The simplest solution is to supplement the AO system using the LGS with a tip/tilt corrector set on a (generally) faint close NGS (V=17 or brighter). Performance is then limited by the poor photon statistics for correcting the tip/tilt error. The need of a natural guide star for tip-tilt sensing is the reason why sky coverage cannot go up to 100% for LGS-AO.

The Laser Guide Star Facility (LGSF) at UT4 is a joint project in which ESO built the laser room, beam relay and launch telescope while MPE and MPIA provided the laser itself.

The PARSEC project is based on a 4W CW Sodium Laser (589.5 nm), focused at 90 km altitude in the mesosphere. The thin layer of atomic sodium present at that height backscatters the spot image and produces, in best conditions, a V~11 artificial star to guide the AO servo loop. More typically, the artificial guide star is in the range V ~ 11-13. This artificial reference star can be created at the position specified by the target coordinates, and the NAOS visible wavefront sensor is used to correct the high order wavefront aberrations on the target object.

The laser is hosted in a dedicated laboratory under the Nasmyth platform of UT4 (Figure 4-2). A custom-made single mode fibre carries the high laser power to the 50 cm launch telescope situated on top of the secondary mirror assembly, providing the best possible artificial source image quality. As a safety measure, a twin whole-sky camera with specialized software is used to monitor incoming aircraft and shut down the laser beam when an airplane enters field of view of the telescope.

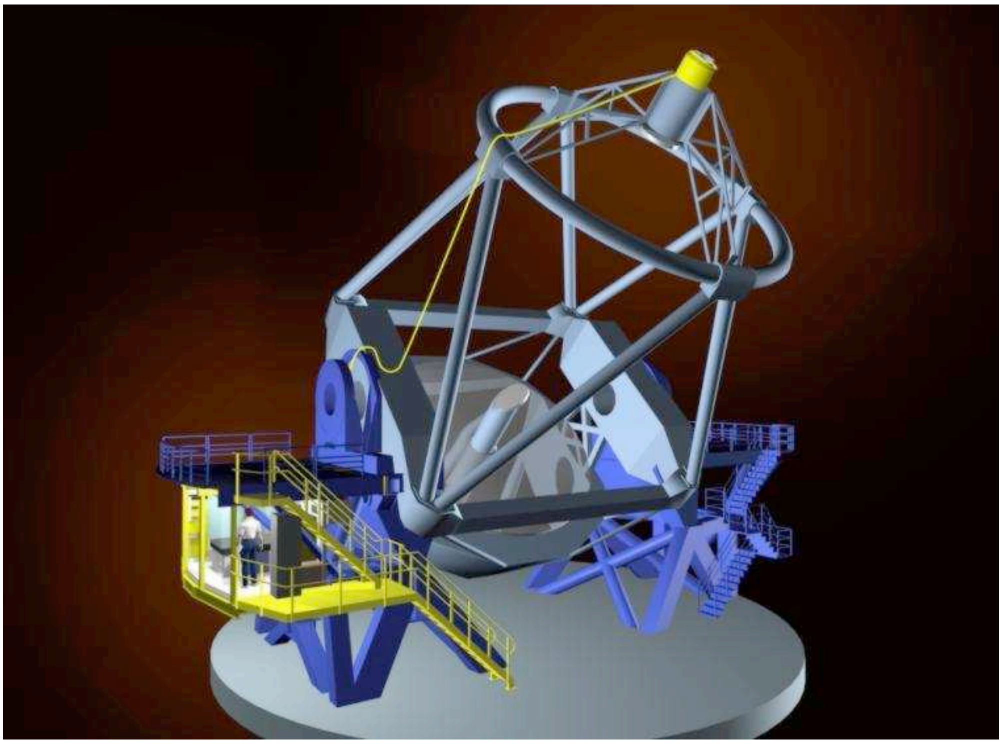


Figure 4-2 Illustration of the LGSF set-up at UT4: the laser clean room is installed below Nasmyth A (note that NaCo itself is installed at Nasmyth B). The laser beam is propagated via fibre to the launch telescope installed at the back of M2.

5 CONICA

CONICA is an IR (1–5 μm) imager and spectrograph, which is fed by NAOS. It is capable of imaging (including Simultaneous Differential Imaging), long slit spectroscopy, coronagraphy, polarimetry and Sparse Aperture Masking observations with several different plate scales. This section describes the optical components of CONICA. See Figure 5-1 for a drawing of the instrument.

The optical path includes the following components:

- The slider wheel, which is either open or closed in calibration position or with the Half Wave Plate inserted.
- The mask/slit wheel, which contains various masks for imaging, SDI+ and polarimetry (note that now only the Wollaston_00 is available, since the Wollaston 45 mask had to be removed to make space for the 4QPM in H and K), the coronagraphic masks and the slits for spectroscopy.
- The Fabry-Perot wheel, which is set to open for non FPI-observations.
- The Lyot wheel, which includes the ND filters and the SAM masks.
- The grism wheel, which contains the grisms, the prism, the SDI+ Wollaston, the Wollaston_00 for polarimetry and the J broadband filter.
- The first filter wheel, which contains all the intermediate band (IB) filters, NB_2.17, NB_2.12 and NB_4.05.
- The second filter wheel, which contains all the broadband filters (except J), the remaining NB filters, and the order sorting filters used in spectroscopy.
- The camera wheel, which contains all the objectives.

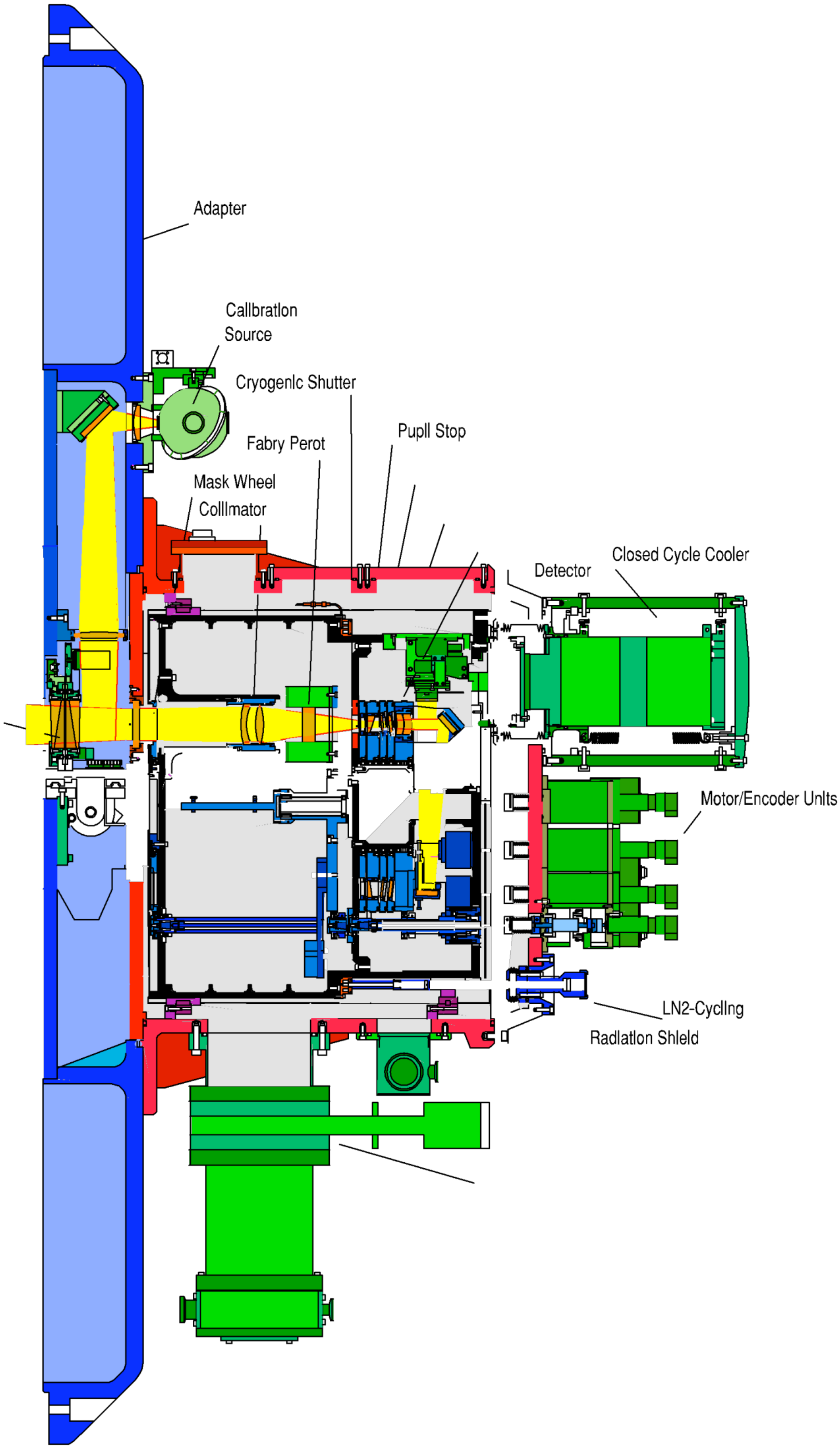


Figure 5-1: CONICA Schematic overview

5.1 Imaging

Imaging and SDI+ (Simultaneous Differential Imaging) uses different combinations of filters, and cameras.

5.1.1 Cameras

The characteristics of the cameras of CONICA are described in Table 5-1, in terms of plate scale and field-of-view. Each camera has a corresponding field mask that is automatically set by the instrument software. The scales and relative errors for the S13 and S27 SW cameras were measured by B. Sicardy using Pluto's motion against field stars, using an accurate Pluto ephemeris. The errors are 1-sigma, i.e. 68.3% confidence level, obtained by χ^2 tests, with 13 stellar trails for S13 and 31 stellar trails for S27. These numbers are well in agreement with the previously measured values using galactic center data (R. Schedel Thesis). (S27 and S13: B. Sicardy, private communication. S54: C. Lidman).

Table 5-1: List of available Cameras with plate scales, fields of view and wavelength ranges.

Camera	Scale [mas/pixel]	FoV [arcsec]	Spectral Range [microns]
S13	13.221±0.017	14×14	1.0-2.5
S27	27.053±0.019	28×28	1.0-2.5
S54	54.50±0.10	56×56	1.0-2.5
SDI+	17.32	8×8	1.6
L27	27.19	28×28	2.5-5.0
L54	54.9	56×56	2.5-5.0

5.1.2 Filters

All but one of the CONICA filters (Table 5-2 and Table 5-3) are mounted on two filter wheels. Transmission curves of several filters are given in Section 8.1. The J band filter is mounted on a third wheel that also contains the Wollaston prism and the wire grids, so J-band polarimetric observations are not possible with NaCo.

In this manual, filters with central wavelengths longer than 2.5 microns will be referred to as LW filters and filters with wavelengths shorter than 2.5 microns will be referred to as SW filters.

Not all filter and camera combinations are supported. For the S13, S27 and S54 cameras, all SW filters can be used. For the L27 camera the NB_3.74, NB_4.05, Lp and Mp filters can be used. For the L54 camera, only the NB_3.74 and NB_4.05 filters can be used.

Observations with the Mp filter are restricted to a FoV of 14″×14″, corresponding to a detector window of 512×512. The FoV is smaller in Mp than in other LW filters because the background in Mp is considerably higher: the integration time has to be reduced which can only be done by windowing the array.

Information on the CONICA's broadband filters can be found in Table 5-2 and for narrow and intermediate band filters in Table 5-3.

Table 5-2: CONICA Broad Band Imaging filters

Name	λc [μm]	FWHM [μm]	Max. Transmission [%]
J	1.27	0.25	78
H	1.66	0.33	77
Ks	2.18	0.35	70
Lp	3.80	0.62	95
Mp	4.78	0.59	91

Table 5-3: List of narrow and intermediate band filters

Name	λc [μm]	FWHM [μm]	Max. Transmission [%]
NB_1.04	1.040	0.015	62%
NB_1.08	1.083	0.015	65%
NB_1.09	1.094	0.015	64%
NB_1.24	1.237	0.015	60%
NB_1.26	1.257	0.014	60%
NB_1.28	1.282	0.014	67%
NB_1.64	1.644	0.018	47%
NB_1.75	1.748	0.026	72%
NB_2.12	2.122	0.022	55%
NB_2.17	2.166	0.023	52%
NB_3.74	3.740	0.02	92%
NB_4.05	4.051	0.02	89%
IB_2.00	2.000	0.060	68%
IB_2.03	2.030	0.060	64%
IB_2.06	2.060	0.060	66%
IB_2.09	2.090	0.060	62%
IB_2.12	2.120	0.060	59%
IB_2.15	2.150	0.060	60%
IB_2.18	2.180	0.060	61%
IB_2.21	2.210	0.060	58%
IB_2.24	2.240	0.060	57%
IB_2.27	2.270	0.060	51%
IB_2.30	2.300	0.060	55%
IB_2.33	2.330	0.060	54%
IB_2.36	2.360	0.060	56%
IB_2.39	2.390	0.060	53%
IB_2.42	2.420	0.060	52%
IB_2.45	2.450	0.060	57%
IB_2.48	2.480	0.060	53%

Additionally, there are two neutral density filters: ND_Long, which can only be used with LW setups and ND_Short, which can only be used with SW setups. These filters are mounted in another wheel, so they can be used in parallel with other filters to reduce the flux of extremely bright sources. The intensity of sources is reduced by factors of 80 and 50 for the ND_Short and ND_Long filters respectively (Transmission curves are given in Section 8.2).

5.1.3 Calibration Plan for imaging and SDI+

For imaging observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The details are described in the NaCo Calibration Plan.

- Nightly zero points (provided it is clear) in J, H and Ks with the S27 objective and visual dichroic. Zero points in Lp and Mp with the L27 objective and zero points in the J, H and Ks filters with either the S13 or S54 objectives and other dichroics will be taken when these modes are used. Observations in J, H and Ks will be done with the detector in Double_RdRstRd and observations in Lp and Mp will be done in Uncorr. Zero points in all other filters and readout modes are not supported by the calibration plan, and users should prepare the necessary OBs. These calibrations aim to provide a photometric accuracy of 5%. Users needing higher accuracy should provide standard stars OBs that will be executed either immediately before or after their observations. The time spent doing these observations will be charged to the user.
- Extinction coefficients for J, H and Ks filters. The observatory does not measure extinction every night. Instead, the observatory has calculated the average extinction from data that have been taken since operations began (E. Mason et al., *Paranal NIR Extinction Coefficients,* in the Proceedings of the 2007 ESO Instrument Calibration Workshop, p 439-442, Springer)
- Twilight Flat Fields in all filters. Observations in J, H and Ks will be taken with the detector in Double_RdRstRd, observations in Mp, Lp, NB_3.74 and NB_4.05 will be done in Uncorr and observations with the remaining narrow or intermediate band filters will be done in FowlerNsamp. Because of the difficulty in taking twilight flats with NaCo, some setups (filter + objective) may be missed. In these cases, the daytime lamp flats can be used as an alternative.
- Lamp flats in all filters, objectives and readout modes, with the exception of Mp, Lp, NB_3.74 and NB_4.05.
- Detector darks in all readout modes and DITs as required.

5.1.4 Pipeline for imaging

The NACO_img_obs_AutoJitter and the NACO_img_obs_FixedSkyOffset templates are supported by the pipeline. The NACO_img_obs_GenericOffset is only partly supported. Sequences of observations with offsets larger than the field of view (mosaicking) are not reduced by the pipeline. The pipeline also calculates zero points and Strehl ratios for data taken with the NACO_img_cal_StandardStar template, read out noise from detector darks, and it creates master twilight flats, master lamp flats and master dark frames.

5.1.5 Fabry Perot Imager

In P83 Fabry Perot imaging is not offered.

5.1.6 Simultaneous Differential Imaging (SDI+)

The SDI+ mode of CONICA obtains four images through three narrow band filters simultaneously. Two images are taken outside the ~ 1.6μm methane feature (at 1.575 μm and 1.600 μm) and two images are taken inside the feature (both at 1.625 μm). All filters have a FWHM of 25 nm. The plate scale of the SDI+ camera is 17.32 mas/pixel.

As of P82 SDI+ has permanently replaced the "old" SDI, now decommissioned.

In SDI+ the beam splitting is done by means of a double calcite Wollaston with the four images placed on a square. The field of view is 8×8″ (see Figure 5-2). Note that the vertical misalignment of the mask varies with time and cannot be corrected for.

The SDI+ has been designed to detect methane rich objects near very bright stars. To give an approximate idea of the performance, contrasts as high as 30,000 between a bright (H < 7 mag) primary star and methane rich object (T_{eff} < 1000 K) can be obtained in 40 min with a signal-to-noise ratio of 6.

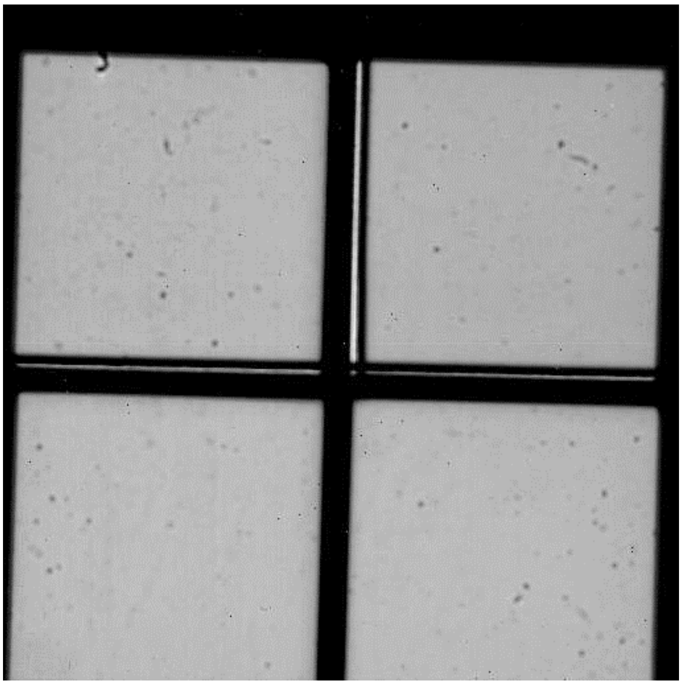


Figure 5-2: Flat field image of the SDI+ mode. The transmitted wavelengths are 1.6 mm (top left), 1.575 mm (top right) and 1.625 mm (bottom left and right).

5.1.7 SDI+ on-sky performance

Figure 5-3 shows the contrast curves (5 sigma) obtained from the reduced SDI+ images of AB Dor. In particular, this is for the first two roll angles of saturated data (DIT=5s, ~17 min total exposure time). We are attaining 5 sigma contrasts of Delta F1(1.575 μm) = 10 mag at 0.5″ and Delta F1(1.575 μm) = 11 mag at 1″, which is comparable, if not slightly better, to the performance of the old SDI device on the same star shown in Figure 5-4 . It is important to note that the contrast curve provided for the old device was with a longer exposure time (~28 minutes), so SDI+ probably can attain a somewhat better contrast than SDI given the same exposure time. For comparison, Figure 5-4 also shows contrast curves for a variety of survey stars (including AB Dor) observed with the old SDI device. The fact that the SDI curve seems to bottom out to a nearly constant value around 2″ suggests that the contrast is read noise limited for radius >2″.

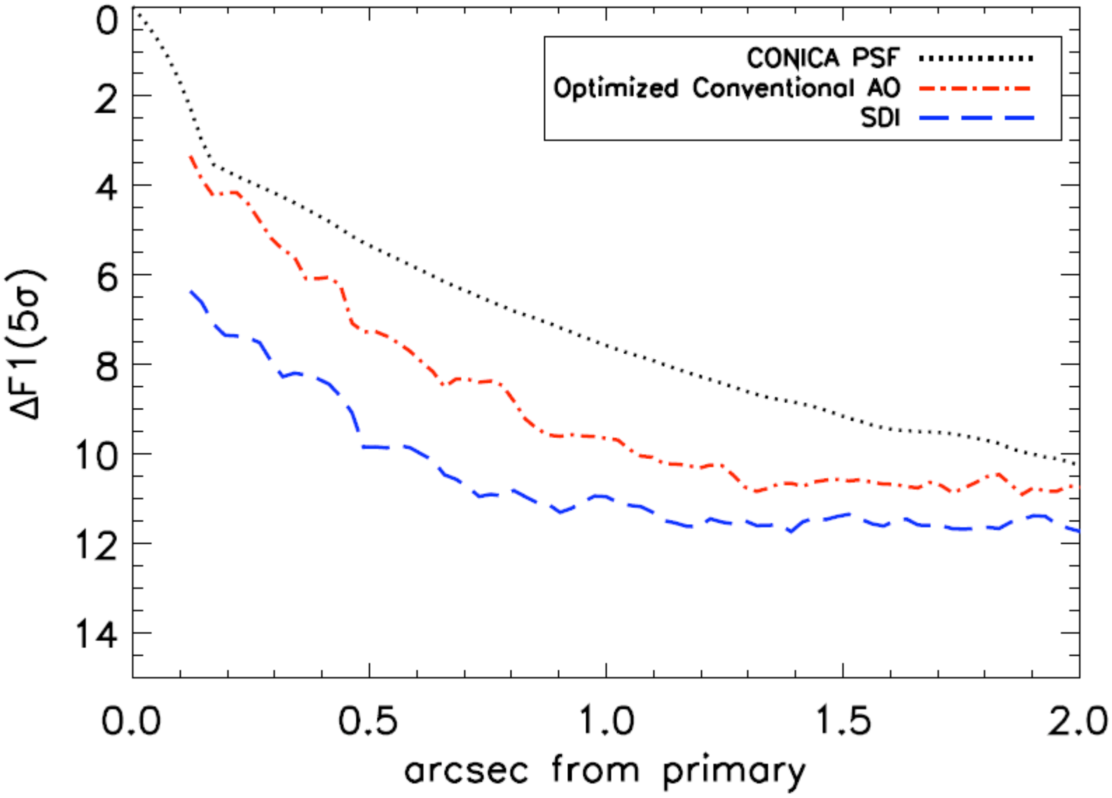


Figure 5-3: Contrast obtained on AB Dor with the new Wollaston (SDI+).

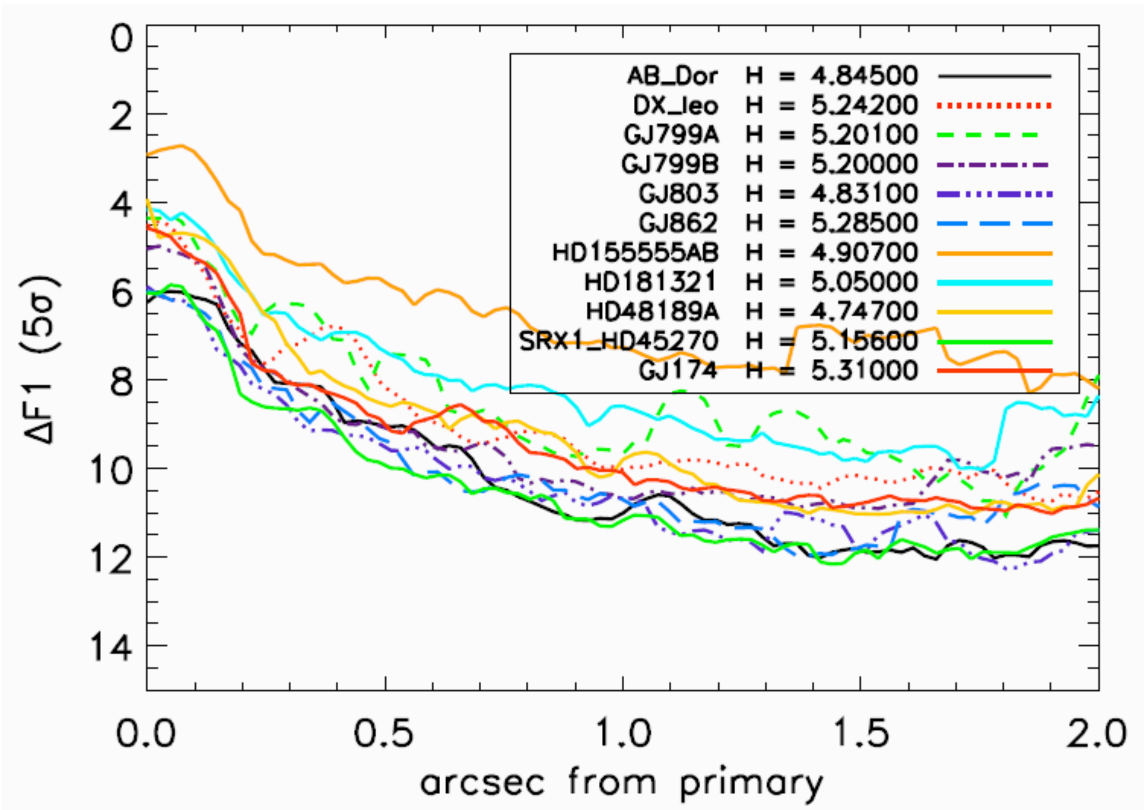


Figure 5-4: obtained on AB Dor with the old Wollaston (SDI, from Biller et al., Ap.J S.S. 173,143, 2007)

5.1.8 Pipeline for SDI+

The SDI+ mode of CONICA is not supported by either a pipeline or an ETC.

5.2 Coronagraphy

For coronagraphic applications, a Lyot-type coronagraph with a circular focal plane mask and an undersized pupil plane mask can be rotated into the beam of CONICA. Five masks are available: two opaque masks with diameters of 0.7 and 1.4 arc seconds, a semi-transparent mask with a diameter of 0.7 arc seconds and two 4 quadrant phase masks (4QPM), one optimized for K-band observations and the other for H-band.

The available masks and their characteristics are listed in Table 5-4.

Table 5-4: CONICA's masks for coronagraphy

Name	Diameter	Comments
C_0.7	0.7″	Opaque, held in place by wires, 100% extinction over the mask
C_1.4	1.4″	
C_0.7_sep_10	0.7″	Semi-transparent (≈ 3.5×10^{-3} transmissivity), placed on a glass plate
4QPM_K	0.15″	Four-quadrant phase mask for K band (13×13" FoV). The diameter is that of the central Lyot spot.
4QPM_H	0.15″	Four-quadrant phase mask for H band (8×8" FoV). The diameter is that of the central Lyot spot.

5.2.1 Performance of the semitransparent mask C_0.7_sep_10

The contrast between inside and outside of the 0.7" semi-transparent mask has been measured to be ΔKs = 6.3 ± 0.1 mags and ΔH = 6.0 ± 0.1 mags. The opaque masks are held by wires and the semi-transparent mask is placed on a transparent plate.

5.2.2 Performance of the 4QPMs

The two four-quadrant phase masks (4QPM) reduce the intensity of a source by adding a phase shift of π to the wavefront. Unlike the classical Lyot masks, a phase mask coronagraph splits the focal plane into four equal areas, two of which are phase-shifted by π. As a consequence, a destructive interference occurs in the relayed pupil and the on-axis starlight rejected outside the geometric pupil is filtered with a diaphragm, a Lyot stop of 0.15" diameter. The advantage over a classical Lyot mask is twofold: there is no large opaque area at the centre, enabling observations of objects that are within 0.35" of the main source, and a larger achievable contrast is met (cfr. Boccaletti et al., *The four- quadrant phase mask coronagraph*, PASP, 116, p. 1061, 2004).

There are two such masks available (Figure 5-5):

- 4QPM_H - optimized for a wavelength of 1.60 μm, circular field of view 8" diameter.
- 4QPM_K - optimized for a wavelength of 2.18 μm, circular field of view 13" diameter.

These devices work best for filters that are centred at or near these wavelengths.

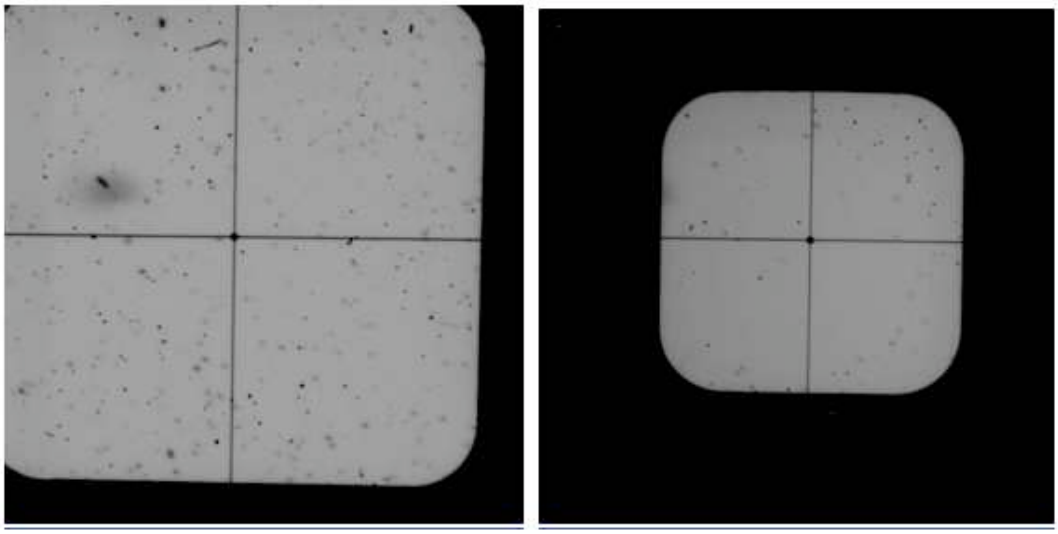


Figure 5-5: Flat field images of the 4QPM_K + Ks filter (left) and of the 4QPM_H + H filter (right). The many dust particles observed in the flats generate flat-field variations of 10-20% locally.

5.2.3 Radial attenuation of 4QPMs

The intensity of off-centred sources is also partially reduced. The radial attenuation was measured to evaluate the impact of the Lyot spot on the Inner Working Angle and hence on the attenuation of an off-axis point source. Measurements were made for both masks and are presented in Figure 5-6: these plots are important to correct the photometry of off-axis objects when looking at close companions. For instance, a companion lying at 0.1″ from the primary has its flux absorbed by 50% in the Ks band and 40% in the H band.

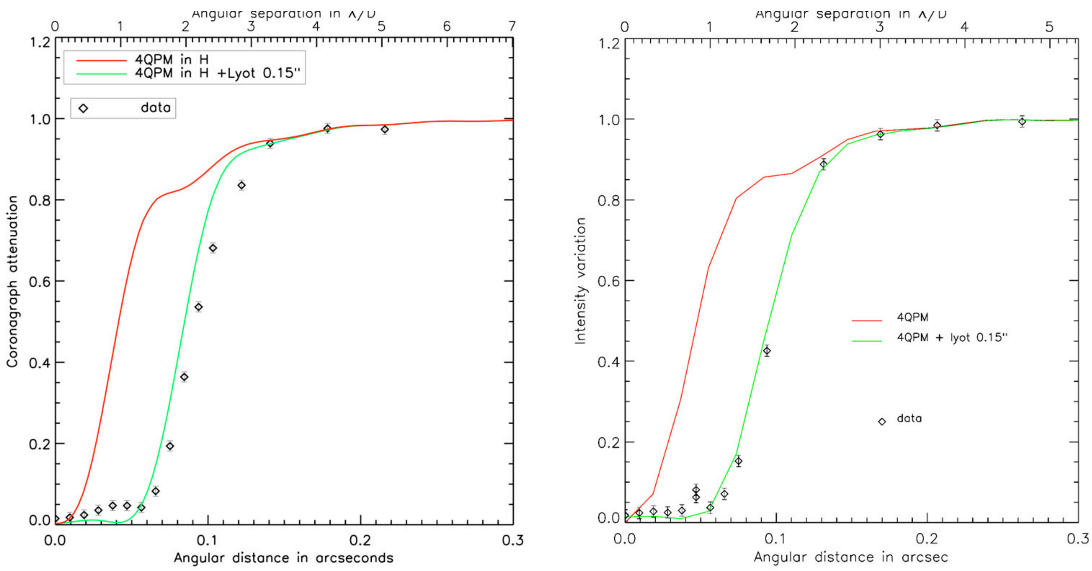


Figure 5-6: Radial attenuation of an off-axis point source moved outwards of the mask centre in H (left) and Ks (right). The data are shown as symbols and the lines are from simulations. Error bars correspond to the uncertainty in the intensity normalization with respect to the simulations. The upper abscissa gives the angular separation in units of λ/D

5.2.4 Contrast of 4QPMs

Contrasts were measured on the PSF fibre for the 4QPM_K and the 4QPM_H. Azimuthally averaged radial profiles are shown in Figure 5-7 and provide an averaged contrast.

Another metric commonly used is the maximum attenuation, which refers to the ratio of the maximum intensity in the PSF image to that of the coronagraphic image. Although maximum intensity is at r=0 on the PSF it is located at 1.5-2 λ/D on the coronagraphic image. Radial contrast does not reflect directly this value because of azimuthal averaging.

The maximum attenuation is about 100, a little bit more in the H band probably because the Lyot spot is larger with respect to λ/D at shorter wavelengths. This is comparable to the result obtained in 2004 with the first 4QPM implemented in NaCo. In this case, the limit of contrast is set by the residual static aberrations likely originating from non-common path aberrations.

5.2.5 Chromaticity of 4QPMs

Phase shifts as provided by phase masks are chromatic. However, the chromaticity effect must be balanced with other sources of degradations. Chromaticity turns out not to be an issue for NaCo. Even with the fibre source, we observed very small variations as a function of the filter bandwidth as shown in Figure 5-8. The attenuation reaches a factor 60-70 in both Ks and NB_2.17 filters. Under atmospheric seeing the effect of chromaticity is totally negligible and a 4QPM designed for the K band can be used with any narrow to broadband filters in the K band and respectively for the 4QPM designed for the H band.

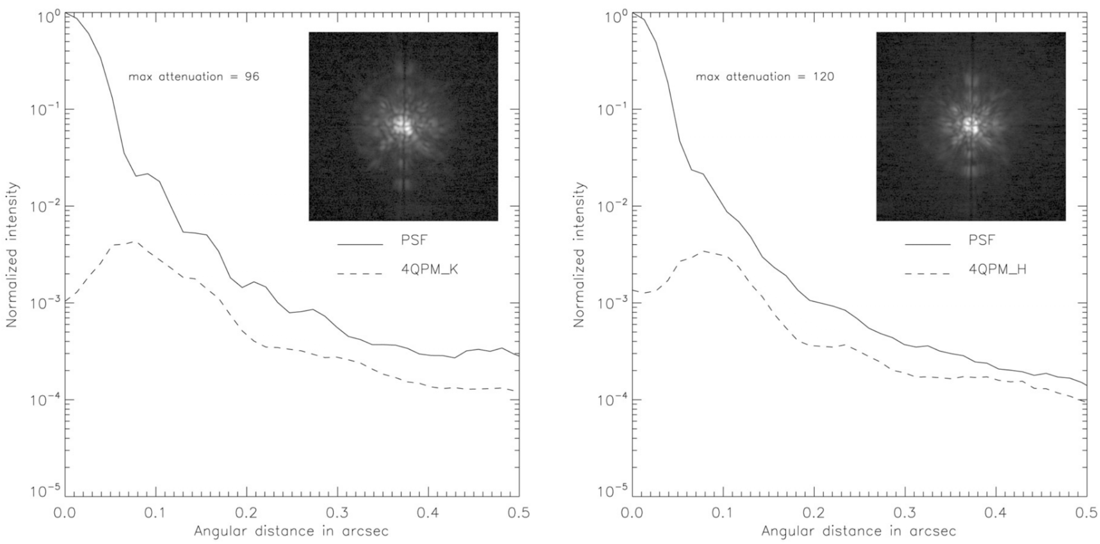


Figure 5-7: Radial profiles of the PSF compared to that of the coronagraphic image obtained with the 4QPM_K (left) and the 4QPM_H (right).

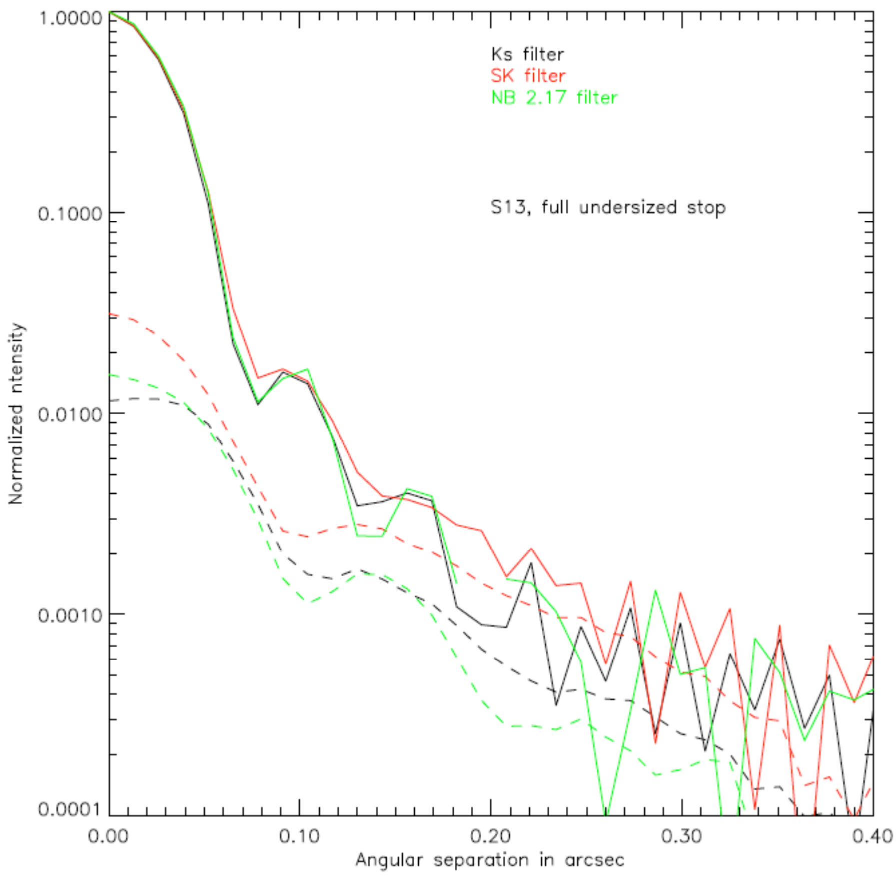


Figure 5-8: Chromaticity of the 4QPM_K measured on the 2004 mask with a fibre (i.e. no seeing effects).

5.2.6 Comparison with the classic Lyot masks

Measurements were made in 2004 and are still valid for the new masks. Figure 5-9 shows data obtained on a natural star. The maximum attenuation is only a factor 10 with the 4QPM while it reaches typically 200 with the 0.7 Lyot therefore allowing deeper integrations. However, the Lyot mask is blind over an area 4 times larger than the 4QPM near the centre and that is precisely the interest of the 4QPMs.

5.2.7 Observing strategy with the 4QPMs.

The precise centring of the science target behind the focal plane mask is critical for the success of the coronagraphic observations, and it is done interactively during the acquisition template. It can also be tuned during the execution of the observing templates.

In general, the mask centres do not coincide with the centre of the chip and the field of view can be vignetted in complex ways. Both the centre and the amount of vignetting depend on the mask and the objective.

Coronagraphic images with 4QPM and broadband filters provide a marginal improvement of contrast at a given radius although a significant maximum attenuation (20-200 depending on coronagraphs) enable large signal to noise ratio with no need of saturation. A large fraction of the flux is therefore left in the focal plane composed with a dynamical halo averaging over time (and fluctuating too) plus a quasi-static halo corresponding to optical aberrations along the optical train (from telescope to detector).

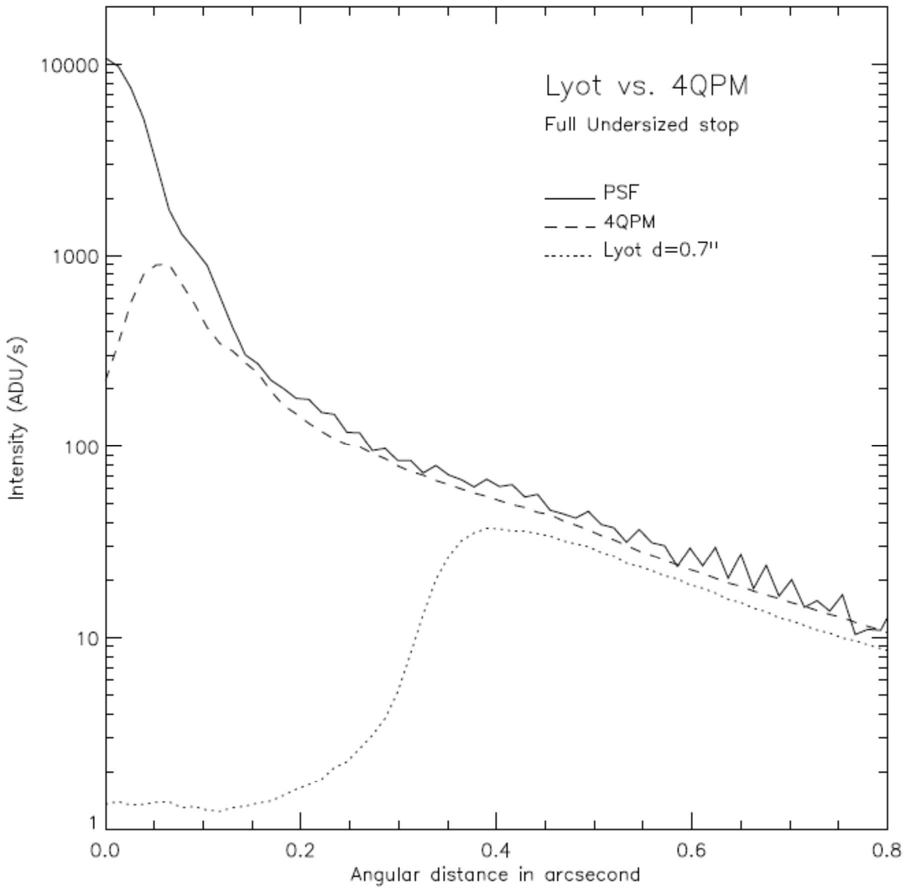


Figure 5-9: Radial profile for the PSF, the 4QPM and the 0.7" Lyot obtained with a natural star in 2004.

It is recommended here to observe a reference star to calibrate these 2 halos. The reference star is chosen with same visible and IR magnitudes to ensure similar AO correction and similar S/N in the image. More important, the reference MUST be observed with the same parallactic angle to have the same static speckle pattern (which result from interaction between telescope and instrument aberrations) and to match the spider spikes position in the images. In practice, the reference star has the same declination as the target but a right ascension, which is that of the star plus or minus the OB duration (the reference is observed for the same amount of time as the target). In general, it is possible to find a reference star within less than 1 degree in declination and a few minutes in right ascension. In these conditions an improvement of a factor 10 can be expected on the averaged contrast. A contrast of 9 to 9.5 mags is achievable at 0.5″ separation in H and Ks. Alternatively, as of P82, one can observe in pupil tracking mode, setting the position of the telescope spiders to the same fixed angle for both the science and the reference stars. In this mode, the field of view rotates from one image to the other and frames will have to be restacked during data reduction.

Given the above, the use of the four-quadrant phase mask is restricted to **Visitor Mode** observations.

5.2.8 Calibration plan for coronagraphy

For coronagraphic observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The calibrations are described in detail in the NaCo Calibration Plan

- Twilight flats and daytime lamp flats as described in 5.1.3. These calibrations are done without the focal plane masks. For additional details, see also Section 5.2.9.

- Detector darks in all readout modes and DITs.

5.2.9 Night flat fields for coronagraphy

Imperfections on the plates that hold the semi-transparent Lyot mask and the 4QPMs together with instrument flexure means that flat fields depend on the rotator angle. The template NACO_coro_cal_NightCalib allows one to take nighttime flat fields immediately after coronagraphic data have been taken. We strongly recommend that these calibrations be taken for the said masks if one wants more than the one pair of on-off images taken during acquisition. Nighttime flat fields with the fully opaque masks are not needed. These flats are taken without the mask.

Given the low transmissivity of the semi-transparent spot, it is practically impossible to normalise the response of the spot relative to the response outside it, i.e. absolute flat fielding inside the spot is very difficult. One can remove the pixel-to-pixel sensitivity variations by using a flat that is taken without the coronagraphic plate, but this kind of flat does not remove dust/features that are on the plate.

As of P82 a new version of the coronagraphic acquisition template for all masks supported by a glass substrate (C_0.7_sep_10, 4QPMs) will take one flat-on and one flat-off image. Those can be used for flat fielding of the science data taken afterwards, since the mask is not moved out of the beam.

5.2.10 Pipeline for coronagraphy

Coronagraphic observations are not supported by the pipeline.

5.3 Simultaneous Differential Imaging plus coronagraphy (SDI+4)

SDI+4 is a new mode of NaCo, offered as of P81 (April 2008). It was commissioned, together with the new 4QPMs by a team from LESIA, Observatoire de Paris, led by A. Boccaletti and collaborators (J. Baudrand, P. Riaud and P. Baudoz).

The SDI+ mode of CONICA can be combined with the 4 quadrants phase mask optimized for the H band to achieve high contrast and improve the detectability of faint sub-stellar companions near bright stars, ideally down to massive extra solar giant planets, by reducing the photon noise at small angular separations. The advantages of this new mode are:

- It allows deeper integration (by about a factor 50-100) with respect to conventional imaging with SDI (unsaturated).
- It allows getting closer to the central star.

An example flat field is shown in Figure 5-10.

This mode is now completely commissioned, and is offered only in **VM** as of P81.

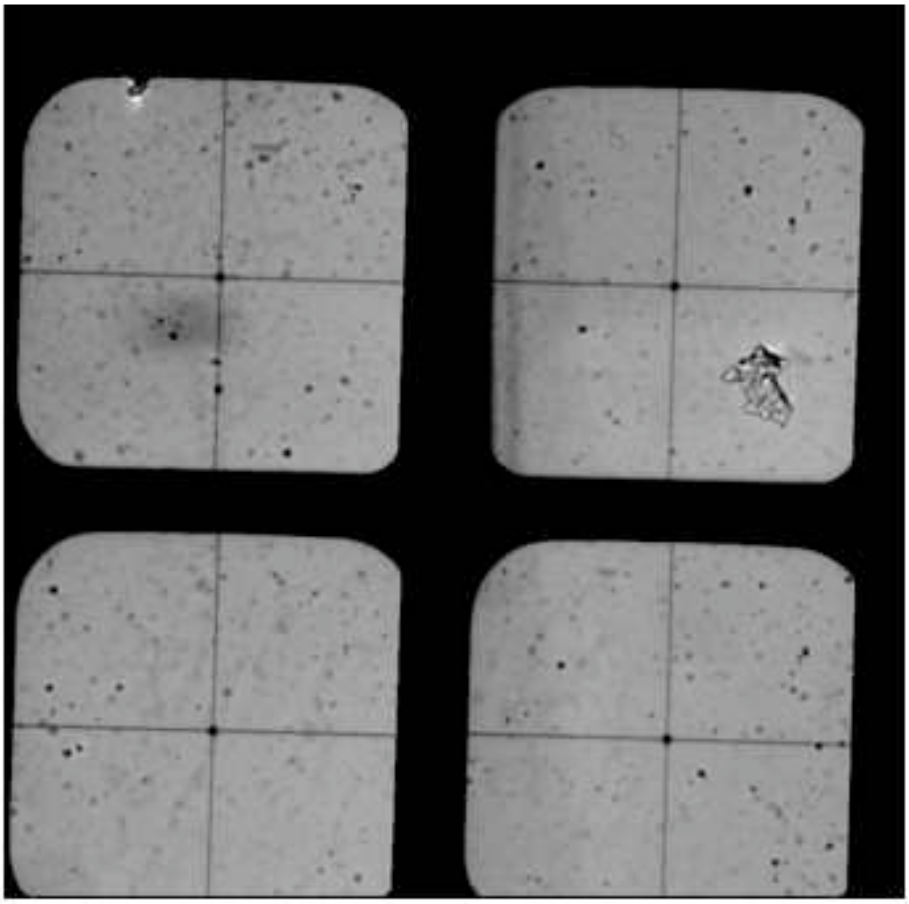


Figure 5-10: Flat field of the SDI+4, corrected from detector flat field taken with the H filter only (not SDI filters). The FoV is 8″ for each quadrant.

5.3.1 Contrast with SDI+4

The contrast when combining the 4QPM_H with SDI and SDI+ was measured. The measurements were done as follows: Gaussian fitting was used to determine accurately the position of the PSFs in order to measure the relative positions between the 4 images. These images were extracted and re-centred at the sub-pixels precision using the result of the Gaussian fitting. Sub-images were over-sampled to improve alignment if needed and to allow better spectral rescaling.

Images are numbered from 0 to 3 starting from the lower left corner and turning anticlockwise with $\lambda_0 = \lambda_1 = 1.625\mu m$, $\lambda_2 = 1.575\mu m$ and $\lambda_3 = 1.600\mu m$ We computed: $(\lambda_0 - \lambda_2)$, $(\lambda_0 - \lambda_3)$, $(\lambda_1 - \lambda_2)$, $(\lambda_1 - \lambda_3)$ (normalization to total intensity). The results are displayed in Figure 5-11. The dotted line corresponding to the 4QPM alone is identical to Figure 5-7 except near the centre because the bandwidth is much smaller than previously and therefore the spectral leakage at the centre is smaller with SDI. There is a clear improvement of almost a factor of 10 to use a 4QPM with SDI at high Strehl regime. In addition to the fact that the signal to noise ratio is improved since longer integration times are possible, the use of a coronagraph is known to be theoretically more favourable to differential imaging as demonstrated here.

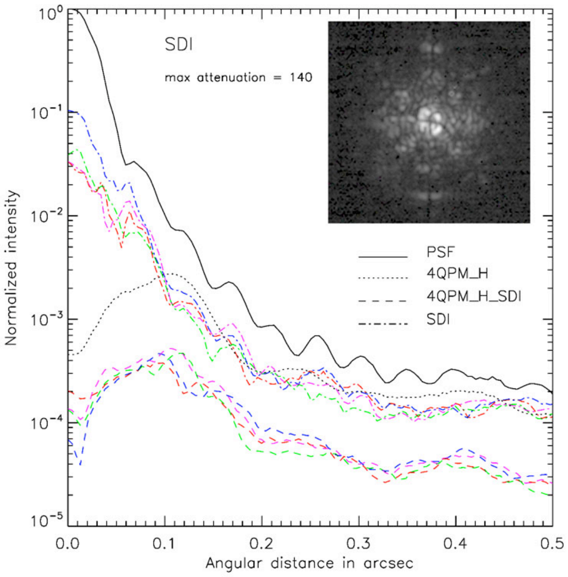


Figure 5-11: Radial profiles for the PSF (solid), the 4QPM image (dotted), and the SDI processing for PSFs (dash-dotted) and 4QPM images (dashed). Colors are for $\lambda_0 - \lambda_2$ (red), $\lambda_0 - \lambda_3$ (green), $\lambda_1 - \lambda_2$ (blue), $\lambda_1 - \lambda_3$ (purple). Left plot is for SDI and right plot is for SDI+.

5.3.2 Tests with 4QPM, SDI+4 and rotation

In the following section the relative merits of different observing techniques with 4QPM and SDI+4 are discussed: this analysis was performed by the commissioning team. The tests were performed on sky, on a star and a reference and the results presented in Figure 5-12. In this figure, we compare the detection levels that can be reached with the classical (no SDI) coronagraphic imaging (using reference subtraction or not), with SDI+4 (using subtraction of SDI images of the reference or not). The effect of roll averaging is also studied. The reference subtraction is only done on 3/4th of the data (8 images out of 11) to match the parallactic angle of the star and its reference.

In Figure 5-12, the SDI processing (solid green) appears to be slightly better for the short angular separation (less than 0.4) than the coronagraphic imaging using subtraction of a reference star (dotted black). To see the effect of the rotation, we added the different images we recorded after correcting for the instrument rotation in order to add up companion signal while averaging out speckle and readout noise. The effect is clearly an improvement of the detection capability especially at large angular distances (dashed green).

The subtraction of the SDI image of the star with the SDI image of the reference star (solid red) was also investigated. This technique is more efficient than the SDI image at angular distance shorter than 1″ and is the same further away. Roll averaging improves also the detection capability of the instrument (dashed red).

The standard SDI processing that consists in 2 observations at 2 roll angles separated by 33º is also given in blue, but for 25º apart. This results in a small improvement with respect to SDI (green line).

Another technique, which is called double roll subtraction, has been tested (dashed blue). It consists in using only SDI data of the star and subtracting the SDI star data to themselves but with different angular separations.

For example, we calculate the images that have a separation of 25º: SDI(0º) - SDI(25º) and SDI(5º) - SDI(30º) and SDI(10º) - SDI(35º), etc up to SDI(25º) - SDI(50º). Adding them after having rotated them by the right amount will add up the information of the companion. However, we have only added 6 times the information of the companion while we have a total of 11 images (and subtracted out 6 images). To add up the other 5 images, we can for example subtract from the 5 images that have not been added yet (SDI(30º) to SDI(50º), note that they were used for subtraction, though) the images that show an angle difference of -25º: SDI(50º) - SDI(25º) , SDI(45º) - SDI(20º), etc to SDI(30º) - SDI(5º). Adding all these roll-subtracted images corrected for the instrument angle will create a typical spatial structure made of a positive PSF at the companion position and 2 negative PSF located at 25º on each side of the companion. The profile in Figure 5-12 clearly shows an improvement of about 1 mag with respect to standard SDI data reduction (SDI + 2 rolls).

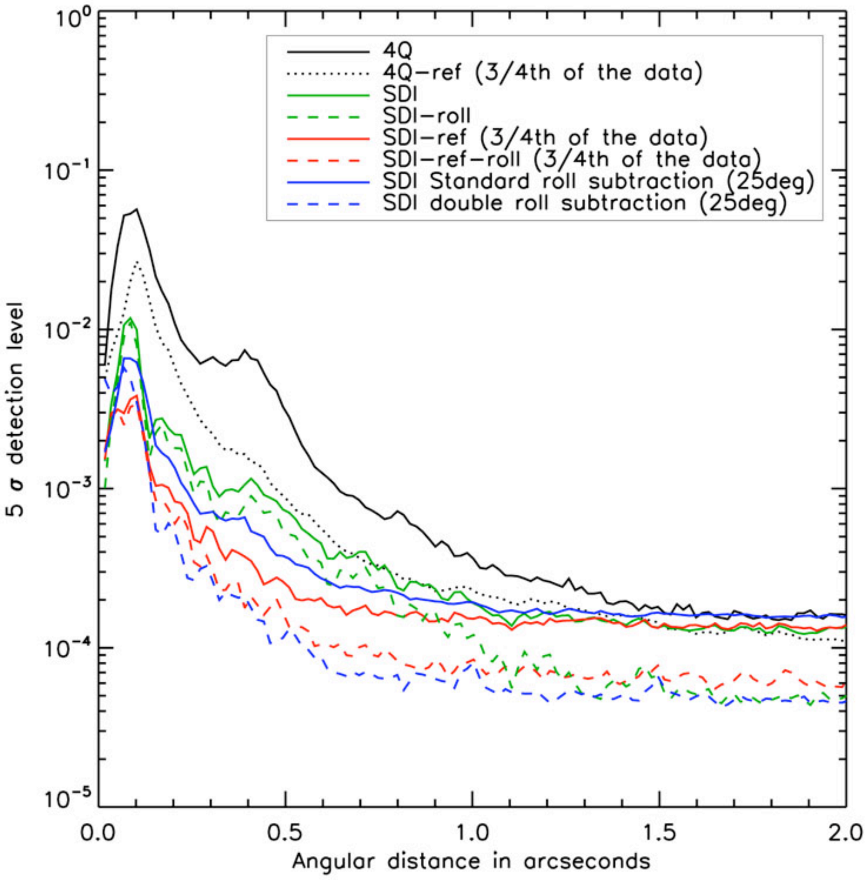


Figure 5-12: 5-σ detection level for different processing techniques. 4Q and 4Q-ref stand for direct coronagraphic imaging respectively not using and using reference subtraction. For all the lines that are called SDI, we are studying the spectral subtraction (image at λ = 1.575µm - image at λ = 1.625µm). SDI and SDI-roll show the results of SDI subtraction with and without roll averaging. It is the same for SDI-ref and SDI-ref roll but using also the subtraction of the SDI image of a reference star at the same parallactic angle. The SDI double subtraction is described in details in the text. For the detection level estimation, we supposed that the companion has a contrast of 100% in the methane band (no flux in the image at λ = 1.625µm).

Obviously, for a companion located at close angular separation, the PSFs may overlap and subtract themselves.

In our case, a simple simulation using the real PSF image has been used to estimate the attenuation of the positive PSF. For an angle of 25º, the PSF is attenuated by 20% at 150 mas and less than 4% at 300 mas. The blue curve showed in Figure 5-12 has been corrected for this effect by dividing the detection level calculated on the double roll subtraction images by the theoretical attenuation. This last technique is outperforming all the others except at very short angular separation (less than 0.15″) where the SDI subtracted by an SDI reference is better. However, since it does not use a reference image, the exposure time on the studied star is doubled for a given observing time. For this reason, we advise users to save images with rotation steps of the instrument and use this double roll subtraction technique to improve the efficiency of the instrument. In terms of operations, the rotation of the instrument is already implemented in the templates and is not time consuming. However during the rotation, the position of the star is changed compared to the coronagraph mask and a re-centring is mandatory, albeit time consuming.

5.3.3 Calibration plan for SDI+4

Darks with the same DIT are the only supported calibration. See also Section 5.3.4.

5.3.4 Night flat fields for SDI+4

SDI+4 is even more affected by dust than those of 4QPMs. The same recommendations issued for 4QPMs hold for SDI+4.

Imperfections on the plates that hold the 4QPMs together with instrument flexure means that flat fields depend on the rotator angle. For this reason, the template NACO_coro_cal_NightCalib allows one to take nighttime flat fields immediately after SDI+4 data have been taken. We strongly recommend that these calibrations are taken for the said setup. In addition the acquisition template for SDI+4 (NACO_img_acq_SDIMoveToMask) takes the following calibration frames:

- One flat-on and one flat-off image with the mask inserted. Those can be used for flat fielding of the science data taken afterwards, since the mask is not moved out of the beam.
- Two images of the bright star off the mask (with ND_Short inserted if needed in acquisition). The second image is meant to be used as sky.

5.3.5 Pipeline for SDI+4

SDI+4 observations are not supported by the pipeline or by the ETC.

5.4 Grism Spectroscopy

Table 5-5 summarizes the main characteristics of the long slit spectroscopic modes. A spectroscopic mode is made up of a grism, an order sorting filter and an objective. The mode name is the identifier given to the mode and it is used in P2PP.

The resolution R is computed for the 86 mas slit. For slitless spectroscopy and for spectroscopy with the 172 mas slit, the spectral resolution is set by the PSF. SJ, SH, SK, SHK and SL are special broad-band filters for spectroscopic applications. They cover a wider wavelength range than the standard J-, H-, Ks- and L-band filters, respectively. The L-band filter is only offered in spectroscopy, for imaging applications users should use the Lp filter.

Table 5-5: Spectroscopic modes. The mode name consists of the objective, the grism number and the order-sorting filter.

Mode	Spectral domain [microns]	Order	Spatial scale [mas/pixel]	Linear Dispersion [nm/pixel]	R
S54_4_SJ[1]	0.91–1.40	1	54	2.00	400
S54_ 3_SH[1]	1.37–1.84	3	54	0.69	1500
S27_3_SH	1.37–1.72	3	27	0.34	1500
S27_4_SH	1.37–1.84	1	27	0.97	500
S54_4_SHK	1.30–2.60	1	54	1.94	550
S54_2_SK	1.79–2.49	2	54	0.97	1400
S27_2_SK	1.79–2.24	2	27	0.49	1400
S54_ 3_SK[1]	1.79–2.57	2	54	1.00	1400
S27_3_SK	2.02–2.53	2	27	0.50	1400
S54_4_SK	1.79–2.57	1	54	1.96	700
L54_1_SL[2]	2.60-4.20	2	54	3.16	700
L27_1_SL[2]	2.60-4.10	2	27	1.57	700
L54_2_SL	3.02-4.20	1	54	2.01	1100
L27_2_SL	3.47-4.20	1	27	1.00	1100
L27_1_L	3.20–3.76	2	27	1.60	700
L54_2_L	3.20-3.76	1	54	2.00	1100
L27_1_LP	3.50–4.10	2	27	1.60	700
L54_2_LP	3.50–4.10	1	54	2.00	1100
L27_2_LP	3.50–4.10	1	27	1.00	1100

5.4.1 Prism spectroscopy

It is possible to do prism spectroscopy in the range 1-5 microns. There are three spectroscopic modes with the prism (See Table 5-6). The spectral resolution varies from about 40, in the J-band, to 250, in the M-band.

[1] Light from the second order can also be seen but does not contaminate.

[2] 3rd order overlap at 3.90 microns.

The L27_P1 mode is difficult to use. The resolution in J is very low and the background in M is high, although it is not so high that normal readout modes cannot be used. For targets with blue colours, it will be difficult to get good S/N at 5 microns without saturating the spectra at 1 micron. Data for the S27_P1 have not been taken.

Table 5-6:Prism spectroscopic modes

Mode Name	Filter	Dispersion [nm/pixel]	Wavelength [microns]	R[1]	Fit [Order]	Fit RMS [nm]
L27_P1	None	8.52[2]	0.85-5.5	90	3	10
L27_P1	None	6.33[3]	0.85-5.5	250	5	2.9
S13_P1	CutOff_2.5μm	4.1	0.85-2.50	60	3	10
S27_P1	CutOff_2.5μm	8.2	0.85-2.50	60	-	-

To select a sub-wavelength range an additional filter can be used. There is a 1-2.5 μm filter (CutOff_2.5μm) that may be used to select the non-thermal range.

The spectral traces of the prism spectra are quite complex. I general one can fit the trace with a 4th order Legendre polynomial, but the coefficients of the polynomial depend on the location of the spectra on the array. The traceS of spectra that are near to the left edge are straighter than those on the right hand side.

The prism introduces an offset in x of approximately 120 pixels with the L27 objective. For the S13 the offset is almost 200 pixels. Figure 5-13 displays a L27_P1 spectrum of a special pinhole. There is some scattered light that appears to come from wavelengths longer than 5.5 μm that may have been introduced by the use of the pinhole rather than being intrinsic to the prism. There are some ghosts but they are most likely reflections. Some are well known detector artifacts.

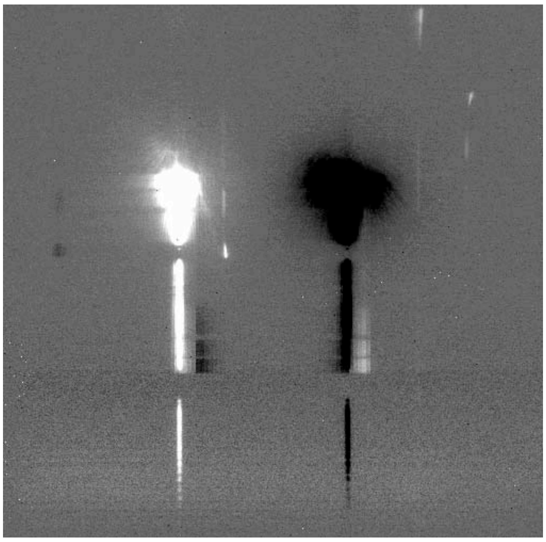


Figure 5-13: a spectrum of an A0 star with the L27_P1 mode. The spectrum starts at 0.85 μm near the top and extends to 5.5 μm near the bottom. Note that the change in brightness from ~5000 ADU and saturated at 1 μm to 20 ADU at 5 μm. One also notes several electronic and optical ghosts.

[1] Based on the 86 mas slit on the central wavelength.

[2] Fit based on spectra taken were taken with several narrow band filters to create pseudo-arc lines. The fit is valid from 1 to 4 microns.

[3] Fit based on telluric absorption features at 5 microns. The fit is valid from 4.5 to 5.5 microns.

5.4.2 Slits

Two long slits and a slitless mode are available for spectroscopy. The characteristics are listed in Table 5-7. Slitless spectroscopy is done with the FLM_13 mask, which is the field mask used for imaging with the S13 objective, and it is available for the SW grism modes only.

The centring of the observed object in the slit (or to the centre of the mask in the case of slitless spectroscopy) is done interactively through an acquisition template.

Table 5-7: Slits in CONICA

Name	Dimensions	Comments
Slit_86mas	86mas × 40″	For the S27 and L27 the slit length is 28″
Slit_172mas	172mas × 40″	For the S27 and the L27 the slit length is 28″
Slitless	14″×14″	Only used for SW modes

5.4.3 Calibration plan (grism spectroscopy only)

For spectroscopic observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The calibrations are described in detail in the NaCo Calibration Plan.

- Telluric Standard Stars. Observations of telluric standards will be performed whenever the grisms are used. Whenever possible, we will limit the airmass difference between the standard and science target to ±0.1 airmasses. The standard will be observed with the setup that was used for the science target. The stars are generally chosen from the Hipparcos catalogue and are either hot stars (spectral type B9 or earlier) or solar type stars (spectral types G0V to G4V). These calibrations are taken so that telluric features can be removed from science spectra. At this point in time, we cannot say how accurate these calibrations will be. Should users wish to use telluric standards of a particular spectral type, they should provide the corresponding OBs and detailed instructions. In this case the time for executing the OBs will be charged to the user and the observatory will not observe a separate telluric standard.
- Spectroscopic lamp flats in all SW spectroscopic modes, slits and readout modes.
- Spectroscopic arcs in all spectroscopic modes and slits. An atlas of lines for the SW modes is available from the NAOS-CONICA web page. LW spectroscopic arcs are not supported. For slitless spectroscopy arcs with the 86 mas slit will be provided.
- Detector darks. Darks are taken at the end of each night with the DITs and readout modes used during the night.

5.4.4 Special notes about the prism calibration

- For the L27_P1 mode, given the low resolution at 1 micron and the high background at 5 microns, the normally used telluric standards (B dwarfs and solar analogs) are not suitable. As a consequence for this mode, two telluric standard stars will be taken as part of the calibration plan. One star adapted to the short wavelength calibration (H=8-9 mag) and one for the Lp and Mp calibration (L=5-6 mag).
- The arc lamps cannot be used to calibrate the dispersion of the prism modes. At long wavelengths, there are no visible arc lines: at short wavelengths, the lines are severely blended.
- One can take spectra with the NB and IB filters to define pseudo-arc lines. The RMS of the fit is relatively large (10 nm). The fit is only good between the bluest and reddest narrow

band filters (currently 1.04 and 4.05) microns. Beyond 4.5 microns, one needs to use the telluric absorption features in the spectra of bright stars. This fit is more satisfying than the fit done with pseudo-arc lines and there might be a possibility of using the very broad telluric features short-ward of 4 microns to use this technique over the entire 1-5 micron wavelength range. However this remains to be tested. Planetary nebulae do not appear to be suitable. At J the resolution is too low and at M the thermal emission from the nebulae dominates.

5.4.5 Nighttime arcs and flat fields

Imperfections in the slits together with instrument flexure means that day time flat fields and arcs depend on the rotator angle. For this reason, the template NACO_spec_cal_NightCalib allows one to take nighttime arcs and flat fields immediately after spectra have been taken. In general, the difference between night and day time calibrations is small and most users will not need to take these calibrations.

5.4.6 Pipeline for spectroscopy

As of P82 we offer a (grism) spectroscopic pipeline. At the time of writing, final tests were still pending. The final product will be a flat-fielded, wavelength calibrated combined spectrum.

Prism spectroscopy is not supported by either and ETC or a pipeline. Users can download an example dataset from the NaCo spectroscopy webpage:

http://www.eso.org/sci/facilities/paranal/instruments/naco/inst/spectro.html

5.5 Polarimetry

A Wollaston prism is available for imaging polarimetry, as well as a turnable half-wave plate. The latter is installed in the entrance wheel of CONICA, where the calibration mirror is situated. Internal calibrations with the half-wave plate are thus impossible.

The Wollaston splits the incoming light into ordinary and extraordinary beams. An image taken with the Wollaston prism will contain two images of every object. To avoid sources overlapping, a special mask, consisting of alternating opaque and transmitting strips, is inserted at the focal plane. In a single exposure, at least half the field will be missing, so that three exposures, with telescope offsets in between, are required to image one field. Sample flat fields with the special polarimetric mask in the focal plane are available from the NaCo web pages.

To measure the Stokes parameters and hence the degree and position angle of polarisation, a second set of images with the Wollaston prism rotated by 45 degrees with respect to the first pair are required. This can be achieved either by rotating the entire instrument or by taking data with the half-wave plate rotated by 22.5 degrees compared to previous data. The beam separations for the different cameras are given in Table 5-8.

The wavelength dependence of the beam separation shows that from 1 to 2.5μm the Wollaston prism can be used for broadband application without loss of spatial resolution. Within the K-band, for example, the resulting chromatic error is about 86 mas.

The Wollaston can also be used with the LW filters; however, the beam separation is less and there is slight overlap between the ordinary and extraordinary beams.

Table 5-8: Beam separation of the Wollaston-prism. The average beam separation corresponds to about 3.3″ on the sky.

Camera	Separation [pixels]
S13	254
S27	124
S54	62

Since the J-band filter is in the same wheel as the Wollaston prism, J-band Polarimetric observations are not possible.

The instrument-induced polarisation, as for all Nasmyth instruments, is a function of the parallactic angle; it is generally of the order of 2%, but can be as high as 4%. If users do not take care in determining the instrument-induced polarisation, then it is not possible to get meaningful estimates of the polarisation, unless sources are more than 3% polarised. In general, we recommend that users come as visitors if they wish to measure the polarisation of sources that are less than 5%. At this stage, we do not know how accurately the instrument-induced polarisation can be removed from data.

5.5.1 Calibration plan for polarimetry

For polarimetric observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The calibrations are described in detail in the NaCo Calibration Plan.

- Twilight flats as described in section 5.1.3. Twilight flats are done without the polarimetric mask and without the polarizer. However in visitor mode, twilight flats with the half-wave plate can be requested.
- Lamp flats as described in section 5.1.3. For polarimetric observations, two sets of flats are taken. For observations with the Wollaston, the first set is without the polarimetric mask and polarizer and the second set is with these elements. There are no internal lamp flats taken with the half-wave plate.
- Detector darks in all readout modes and DITs.

5.5.2 Pipeline for polarimetry

Polarimetry is not supported by the ETC or the pipeline.

5.6 Sparse Aperture interferometric Masks (SAM)

As part of the original design of the CONICA camera, provision was made for the possibility of utilizing aperture masking interferometry in order to obtain the very highest angular resolutions at the diffraction limit. Following highly successful demonstrations of the technique elsewhere, both in the AO-corrected and non-AO case, a proposal was submitted to ESO to install custom-fabricated aperture masks into the pupil wheel of CONICA. SAM was commissioned in March 2008, after a first attempt in Feb. 2007 adversely affected by bad weather, by the PI Peter Tuthill (School of Physics, Sydney University) and his Co-I Sylvestre Lacour (University of Grenoble). The results reported in this manual are taken from their commissioning report.

The design of aperture masks for a telescope needs to take into account several complicating factors. For a given observation, there are trade-offs between various parameters, which means that a range of different masks can be used in order to tailor the experiment to somewhat varying targets and science. The factors relevant to mask design include:

The desired Fourier coverage (especially the shortest & longest baseline required)

The bandwidth of the optical passband to be used for observations

The apparent brightness of the target star

The readout noise properties of the detector

The degree of correction provided by the AO system

In order to span a promising range of observational parameter space, five masks were fabricated and the physical properties of the masks is illustrated in Figure 5-14. They were fabricated by precision laser machining onto 0.2 mm steel stock. The outer diameter of the final masks was 20 mm to fit within the CONICA pupil wheel slots.

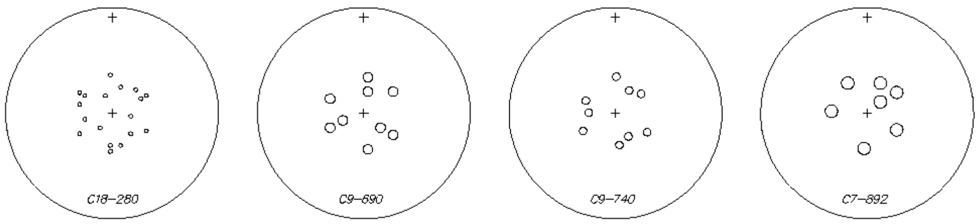


Figure 5-14: Mechanical drawings of the four aperture masks installed in the CONICA camera.

In general, the more holes appear in the mask, then the smaller the holes must be (to preserve non-redundancy) and consequently the less light that is passed by the mask. The mask to the left shows the 18holes configuration which yields excellent Fourier coverage, but which does not pass a large fraction of the incident light. In order to access successively fainter targets, the 9 and 7 holes configurations may be used, although the Fourier coverage becomes markedly worse. There are two different 9-hole configurations: 9holes and BB_9holes. The distinction between these two being that the simple "9holes" offers superior Fourier coverage and slightly higher throughput, but is not suitable for large fractional bandwidth observations. For bandwidths wider than about 10-15%, the "9holes" mask is unsuited and the "BB_9holes" should be used.

The two-dimensional layout of the holes specifies the Fourier coverage afforded by the given mask. This was optimized with a computer parameter space search algorithm that follows from and extends the work of Golay (1970 JOSA 61 272). Exact locations of the holes cut for each mask, together with all relevant dimensions and specifications of the physical masks themselves, have been provided in the NACO SAM web pages:

http://www.eso.org/sci/facilities/paranal/instruments/naco/inst/mask_datasheet.html

A scaled illustration depicting the optical effect of the masks as projected onto the correctly scaled VLT telescope pupil (assuming ideal optical alignment) is given below. The large circumscribed circle represents the outline of the VLT primary mirror, while the smaller centred circle shows the silhouette of the secondary mirror. It is important to note that the spiders, which support the secondary mirror, are not depicted here, but they have an important effect which will be discussed later.

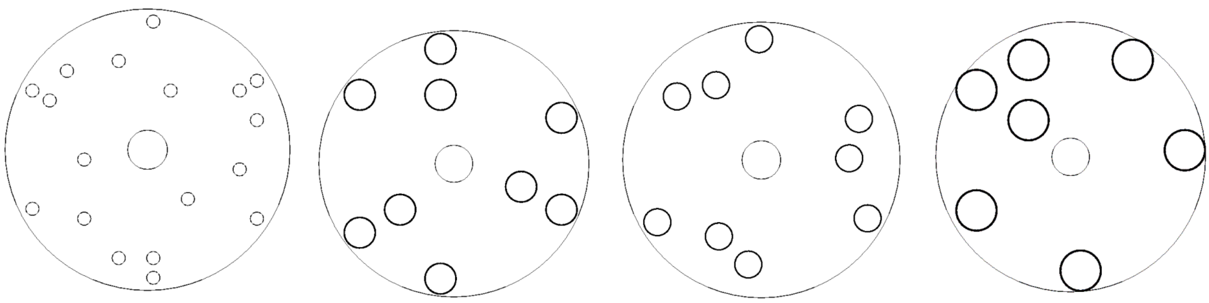


Figure 5-15: Optical diagrams showing the effect of apodizing the pupil with the four 2-dimensional masks implemented in the CONICA camera.

5.6.1 SAM: why and when to use it

Masking is useful for very narrow fields of view (the outer limit is set by the resolution of the shortest baseline in the mask). Any advantages it enjoys over conventional full-pupil imaging are only manifest at such very high resolutions – typically within several resolution elements of the PSF core. In the infrared, this typically means that the scientific niche is for objects where the entire field of interest lies within several hundred milli-arcsecs from a bright star. (Although there may be ways to mosaic larger fields together, these have never been successfully demonstrated).

Key strengths of a dilute and (ideally) non-redundant pupil are in the mitigation of atmospheric phase noise (seeing) and the use of robust, self-calibrating observables such as the Closure Phase. For brevity, we refer the reader to the references (section 5.6.10) for discussion of the philosophical underpinnings that motivate masking interferometry.

Masking is furthermore (by its nature) limited to brighter classes of targets. This is because it is only effective at combating atmospheric phase noise – seeing – and it is counterproductive in photon-starved regimes where detector readout noise dominates. Earlier experiments with seeing-limited telescopes (before the advent of AO) in the near-IR had a magnitude limit of about 5th mag in K-band. With NaCo we estimate that the useful magnitude limit for some types of observations could be as faint as 10-12th mag, depending on the level of correction obtained. Here, we limit our discussion to two basic types of observation: (1) imaging and (2) faint-companion detection. For both of these modes, masking interferometry has demonstrated levels of performance that match or exceed those obtainable by any other means. Further discussion of these strengths can be found in the sections below detailing the on-sky performance obtained with SAM at NaCo.

5.6.2 Pupil tracking with SAM

One additional aspect of experimental implementation that was requested in advance was the ability to drive the optical rotator and telescope control system in such a fashion that the image of the pupil within the CONICA camera is maintained fixed at a given orientation while the telescope tracks and slews to different stars. This "**pupil tracking mode**" is crucial for experiments such as aperture masking, where the occultation of one of the mask holes by the telescope spiders will cause highly detrimental loss of Fourier coverage and compromise the calibration properties of the experiment. Furthermore, for observational programs relying on precision calibration, it is simply good practice to preserve the optical system in a stable configuration between source and reference star.

Although simple in principle (the rotator simply has to track the elevation axis, ignoring the azimuth axis), in practice such a mode can take some effort to fully implement as software driving the pointing, tracking and guiding systems, together with the AO system, all needs to understand the implications of the new sky rotation.

Pupil tracking mode is the default way to observe with SAM and is implemented in a transparent way for the users.

The masks have 120 degrees symmetry, while the telescope spiders have 180 degrees symmetry. In theory it should be possible to find 6 angles at which no overlaps between spiders and mask holes occur and use these 6 setups to observe with the pupil at different orientations: this technique allows avoiding the spider arms falling onto unwanted areas od the detector and achieving the highest possible dynamic range. However, at the time of writing, the telescope pupil and NaCo are not well aligned, and only one angle per mask has been found suitable for use. Better pupil alignment is one of the goals of an upcoming intervention during 2009.

5.6.3 Detector readout and cube mode setup for SAM

For bright targets, the dominant noise term is in the perturbations from the turbulent atmospheric phase screen. Rapid readout of the detector array tends to freeze the motion of the interference fringes, reducing the impact of the seeing on the measured coherence of the incoming wavefront. Thus seeing drives us to read as many rapid-exposure frames as possible, but this needs to be traded off against detector readout noise, which will rapidly dominate for fainter stars. CONICA is ideally suited as a masking camera because it offers a readout mode (DCR/HD) for collecting data cubes of consecutive frames of any given integration time with minimal overheads and high duty cycle. These data cubes typically consist of hundreds of short-exposure (0.1 sec) frames for bright targets, or perhaps a few tens of longer exposure frames (1–10 sec). More details on cube mode can be found in section 5.8.

Given the very small useful science field-of-view, it is generally not necessary to read the entire 1024 pixel array. In fact, normally only a 256x258[1] pixel region would be sufficient. In addition to saving on data storage, the smaller sub-arrays can be read out faster and with a lower-noise readout strategy. Arrays of size 1024, 512 and 256 can be read out in 0.34, 0.11 and 0.04 seconds, respectively (in Double_RdRstRd). Other windows, such as 128×130 and 64×66, are too small to contain the SAM patterns and are not to be used.

Although for some of the brightest targets, there may be good arguments for pursuing a 256x258 sub-array, the 512x514 sub-array is recommended. The main advantage of this is that the image of the science target can be dithered between two separate quadrants on successive data cube integrations. Thus while collecting data in one quadrant, one collects a sky background frame in another quadrant at the same time.

5.6.4 SAM with LW filters

Operation in the 3-5 μm region, using the long-wavelength filters offered within CONICA, is straightforward. This was commissioned using the L27 camera, which adequately samples the fringes, and has optical components optimized for this region. For the shorter wavelength operation, only the S13 was used – again to ensure adequate sampling of the fringes.

Special strategies such as chopping to remove sky fluctuations are generally not essential for long-wavelength aperture masking. One reason is that the masks themselves dramatically cut down the sky background (and stellar target) by a factor ranging from 84 to 96% depending on the mask. Furthermore, thermal anisotropies in the sky tend to be smooth and slowly varying, with little fine-grained structure on scales of tens of milli-arcsec where the interference fringes from the masking are formed.

5.6.5 Choosing which mask to use

The philosophy of aperture masking taken to the extreme would suggest a mask with many tiny holes, each of which makes an almost point-sample of the incoming wavefront. Such a mask would pass very little light, and be useless for all but extremely bright targets. With only 4% throughput, the 18Holes mask is the nearest approximation to this ideal in CONICA, with the other masks having fewer but larger holes, and passing increasingly more light up to a maximum of 16% for the 7Holes mask.

Masks with many closely spaced holes also suffer from a second problem: that of bandwidth smearing. Using a wide optical bandwidth filter, the fringes formed between a pair of holes will

[1] Hardware windowing with the CONICA array requires NY=NX+2, where NX and NY are the number of pixels in X and Y respectively.

occupy a range of spatial frequencies proportional to the bandwidth. This can mean that power from neighbouring baselines can smear into one another, confusing the signals. In general, this means that masks with many holes must also be used with the narrowest bandwidth filter sets. In terms of optical throughput, this therefore gives a double-penalty. The use of the more closely "ideal" masks (many tiny holes) is therefore restricted to quite bright targets.

The primary determinant for which mask to choose in any given situation is the brightness of the stellar target. For bright targets, try for a mask with many small holes (18Holes). For faint targets, a mask with fewer large holes and the ability to observe in the broad filter sets (e.g. BB_9Holes) is likely more optimal.

There can also be secondary issues motivating the choice of a mask. In general, to get enough Fourier coverage to do good mapping of a complex structured target, one should push for a mask with more holes and short minimum baselines to extend the field-of-view. Furthermore, some observations may be needed in specific narrowband filters, or with special setups, and so mask choice can be a complex optimization.

The four commissioned masks are now briefly described in turn. More detailed specifications and hole layouts are given in section 5.6.9.

18Holes: this mask can only be used with the narrow and intermediate (NB, IB) filter sets. Useful range is targets brighter than about 4th Mag. Excellent Fourier coverage for imaging, and should also serve well for faint companion detection.

9Holes: this mask is designed for use with the NB and IB filters, although it may be marginally OK with broadband filters such as Ks, Lp, or Mp. Useful range is from about 3rd to 7th Mag (fainter if bandwidth smearing is not an issue). Gives very good Fourier coverage, and could be used for mapping relatively simple objects. Good for faint companions.

BB_9Holes: this mask was specifically optimized for broadband (hence BB_) operation, and should be used with the broad filter set. Although bandwidth smearing is unavoidable, this mask is not affected because the holes are arranged so that they do not smear into each other. Useful range of target brightness is about 5th to 10th. Fourier coverage is not as good as 9Holes.

7Holes: this mask passes the most light, and should operate from about 8th to 11th or maybe 12th mag. Probably it is most useful for faint companion detection due to limited Fourier coverage.

5.6.6 Calibrations: flat fields and data cleaning

Data processing entails all the normal imaging data tasks such as subtraction of any bias, flat fielding and removal of bad pixels. To obtain flats and bad pixel maps, the standard NaCo calibration plan and pipeline recipes are fine. Results using the standard pipeline reduced flats were compared with flats generated by hand, with the finding that there was no significant difference.

Normally, masking data will be taken in a data cube mode, which yields a large sample of the interferograms (up to several hundred frames). A further data cleaning strategy is based on frame selection over this data cube: any frames with poor AO performance or any other strange effects are rejected. This can be easily achieved by cutting the data according to outliers in simple statistical tests on quantities such as the counts in the peak pixel, the total counts, etc.

5.6.7 PSF calibrations strategies

As with all forms of optical interferometry, it is paramount to preserve a focus on calibration. To do this, it is suggested to bracket observations of the science target with observations of a nearby point-source reference object. Ideally, this reference star will be an unresolved point (or if not, at least a single star of well-known size). Good calibration is helped by observing the reference star(s) at similar airmass and observed with as near-identical telescope/AO configuration as possible. To this end, the SAM template will use the "PSF" flag to keep the AO configuration the same as the one used for the previously observed science object. The pupil position is kept identical, since science and calibrator are observed with the same mask, and each mask has its own assigned pupil angle.

Finding reference stars is straightforward, but does take some work and it may help to consult some local interferometrists, or interferometry web resources (some institutions such as the Michelson Science Center have calibrator-finding catalogue search engines available online). For the case of CONICA, the resolutions are relatively modest so almost all single stars of any spectral type will present photospheres that are essentially unresolved (with the exception only of a handful of extremely bright, red late-M supergiants and Miras). This being the case, a good calibrator is then any star which is single and without an extensive circumstellar dust shell (or if binary, has a relatively wide companion of at least several arcsec).

An attempt should be made as far as possible to preserve the same AO parameters between source and calibrator star. If using the visible wavefront sensor, this can present difficulties, because often science targets will be very red or dusty (to give resolved structure). Finding calibrator stars for such extreme-spectrum objects can be challenging. If we consider an object such as WR 104, which is 14^{th} mag in V but 2^{nd} mag in K, then any normal star with similar IR fluxes will be orders of magnitude too bright for the visible WFS at the same settings. For such targets, it may be necessary to use the IR WFS.

Calibration is further enhanced by taking more rapid exposures, removing the effects of seeing and irregular AO correction from the data.

There are compelling reasons to make multiple visits between the source and calibrator. This will help to beat down the random noise and explore any systematic term in the calibration. Furthermore, Fourier coverage will be enhanced by the sky rotation obtained between successive visits. This is helpful for imaging, but even more crucial for faint-companion detection. The regular sampling grid on which the Fourier data is recorded permits some ambiguity when only a single snapshot is recorded. Wide binaries can masquerade as much closer companions and give false signals. Taking a second or even third visit to an important target helps to eliminate these problems.

5.6.8 SAM imaging tests

For the imaging tests given here, the 18Holes mask was used. This gives the best Fourier coverage and well-sampled short and long baseline data. This means it is well suited to imaging of complex targets, but of course this mask is the least sensitive and so only relatively bright targets are shown here.

Imaging using the 9Holes or other masks may be possible, but the more limited Fourier coverage will limit the complexity of targets that can be mapped well. One way to help circumvent this problem a little would be to observe the object over a period of several hours, with visits alternating between the source and calibrator. This would help build Fourier coverage by Earth rotation synthesis.

In general, errors on the visibilities produced by masking are large. The Fourier amplitude data is therefore quite poor. A large fraction of the success of the images depicted in this section is due to the relatively good *Closure Phase* data. This is an important point to keep in mind, because many targets that one might wish to image do not show large closure phase signals at all. Closure phases arise in situations where the source has non-point-symmetric structure, and so objects such as a spherical shell, and elliptical ring, or an equal binary star, will all give closure phase signals which may be weak or zero everywhere, and thus lead to difficulties in producing a good image.

5.6.9 U-V coverage

This section contains information on the physical dimensions of the sparse aperture masks placed in the CONICA camera. These values are necessary to compute the u-v coverage of the instrument. Assumptions:

- The pupil diameter in the camera is 10 mm.
- The clear aperture of the telescope is assumed 8.00m
- The central obscuration assumed 1.116 m.
- Telescope mirror area = 49.29 m^2

Masks manufactured to fit within slots in the pupil wheel 20 mm outer diameter. Each mask is embossed with an identifier and in addition has orientation marks "+" at the centre and towards the edge. Material: .02 mm steel sheet.

1) Mask"18Holes". Hole size = 0.465 mm diameter

Table 5-9: X and Y location of the holes as measured in mm from the centre of the mask 18Holes.

X	Y
-0.203155	-3.87061
-0.203155	-4.57435
-1.42208	-1.75937
-3.25047	-0.703745
-3.85992	1.05562
-3.85992	-2.46311
3.45362	1.75936
4.06308	2.11124
2.23470	-0.351874
2.23470	-2.46311
1.01577	-3.87061
4.06308	-2.11124
-3.25047	2.11124
-3.85992	2.46311
-0.812615	2.11124
1.01577	3.16686
2.84415	2.81498
-0.203153	4.57435

2) Mask 9Holes". Hole size = 1.156 mm diameter

Table 5-10: X and Y location of the holes as measured in mm from the centre of the mask 9Holes.

X	Y
3.50441	-2.60135
3.50441	2.60135
2.00252	-1.73423
0.500629	-4.33558
0.500631	2.60135
0.500631	4.33558
-2.50315	-0.867115
-4.00503	-1.73423
-4.00503	1.73423

3) Mask: "BB_9Holes. Hole size = 0.980 mm diameter

Table 5-11: X and Y location of the holes as measured in mm from the centre of the mask BB_9Holes

X	Y
-3.18399	0.0607701
-3.53717	1.49530
0.0805017	4.39864
1.64462	2.72703
3.06355	2.31563
3.76908	-2.26903
1.53937	-2.78780
0.473616	-3.81093
-3.84958	-2.12960

4) Mask 7Holes. Hole size = 1.50 mm diameter

Table 5-12: X and Y location of the holes as measured in mm from the centre of the mask 7Holes

X	Y
3.51064	-1.99373
3.51064	2.49014
1.56907	1.36918
1.56907	3.61111
-0.372507	4.23566
-2.31408	3.61111
4.25565	0.248215

5.6.10 References and further readings

We have tried to give brief notes on the practical use of the aperture masks in the CONICA camera. When used correctly, these masks transform the single 8-m telescope pupil into a sparse interferometer array, and it is therefore necessary to understand the principles of optical interferometry and in particular the recovery of complex Fourier data (amplitudes and phases) from the Fizeau interference patterns that result. A full explanation of the mathematical techniques necessary to do this task is beyond the scope of the present document. The reader is advised to consult sources form the open literature concerning aperture masking. Some useful references specific to masking include:

- Tuthill P.G. et. al. "Michelson Interferometry with the Keck I telescope" PASP 112 555 (2000).
- Tuthill P.G. et al. "Sparse-aperture adaptive optics" SPIE 6272 103 (2006).
- Lloyd J.P et. al. "Detection of the Brown Dwarf GJ 802B with Adaptive Optics Masking Interferometry" ApJ 650 131 (2006).

In brief, masking is useful for very narrow fields of view (the outer limit is set by the resolution of the *shortest* baseline in the mask). Any advantages it enjoys over conventional full-pupil imaging are only manifest at such very high resolutions – typically within several resolution elements of the PSF core.

Dynamic ranges obtained within this realm have been demonstrated to be in excess of 200:1 for point source detections. To attain this level of precision, careful analysis of closure phase signals is required and exhaustive understanding of error sources such as PSF calibration and chromatic effects arising from atmospheric dispersion. Furthermore, with full recovery of closure phase signals, complex and arbitrary flux distributions can be mapped with high fidelity. The particular strengths of aperture masking are for relatively bright targets where there is resolved or partially resolved structure within a few resolution elements of bright PSF cores.

The range of masks installed in the camera is intended to span a variety of target fluxes, with the 18-holes mask being tailored to give the best results for bright targets, through to the 7-holes which is for use on the faintest targets. Section 5.6.16 gives calibrations of the counts expected for varying mask/filter combinations.

5.6.11 On sky observations: VY Canis Maioris

VY Canis Majoris is a bright M-supergiant which has produced an extensive infrared nebula several arcsec in extent. At the core, VY CMa exhibits a bright asymmetric plume, first imaged in detail in Monnier et al 1999 (ApJ, 512 351). This form of strongly asymmetric structure, together with the spatial structure on ideal scales of less than 200 milli-arcsec, all makes VY CMa an ideal test target for SAM.

Figure 5-16 shows images produced in narrowband filters within the H and K bands using 18Holes mask data recorded at the commissioning run in March 2008. For comparison, we also show the results of contemporaneous imaging observations using the full telescope pupil and adaptive optics system. We have taken an identical series of rapid exposures to the masking case, and use the shift-and-add algorithm to stack these data into a final resultant best image. This is given in the bottom panel of Figure 5-16. There is some correspondence between the AO-only and masking images, in that there is evidence for a similarly skewed centre of brightness in the AO image. However, the fine detail and diffraction-limited structures appearing in the masking data cannot be seen in the AO image. It is possible that with deconvolution using a carefully recorded PSF frame that more real structure may be recovered from the AO, but this procedure has proved to be controversial in the past, and can lead to spurious structures.

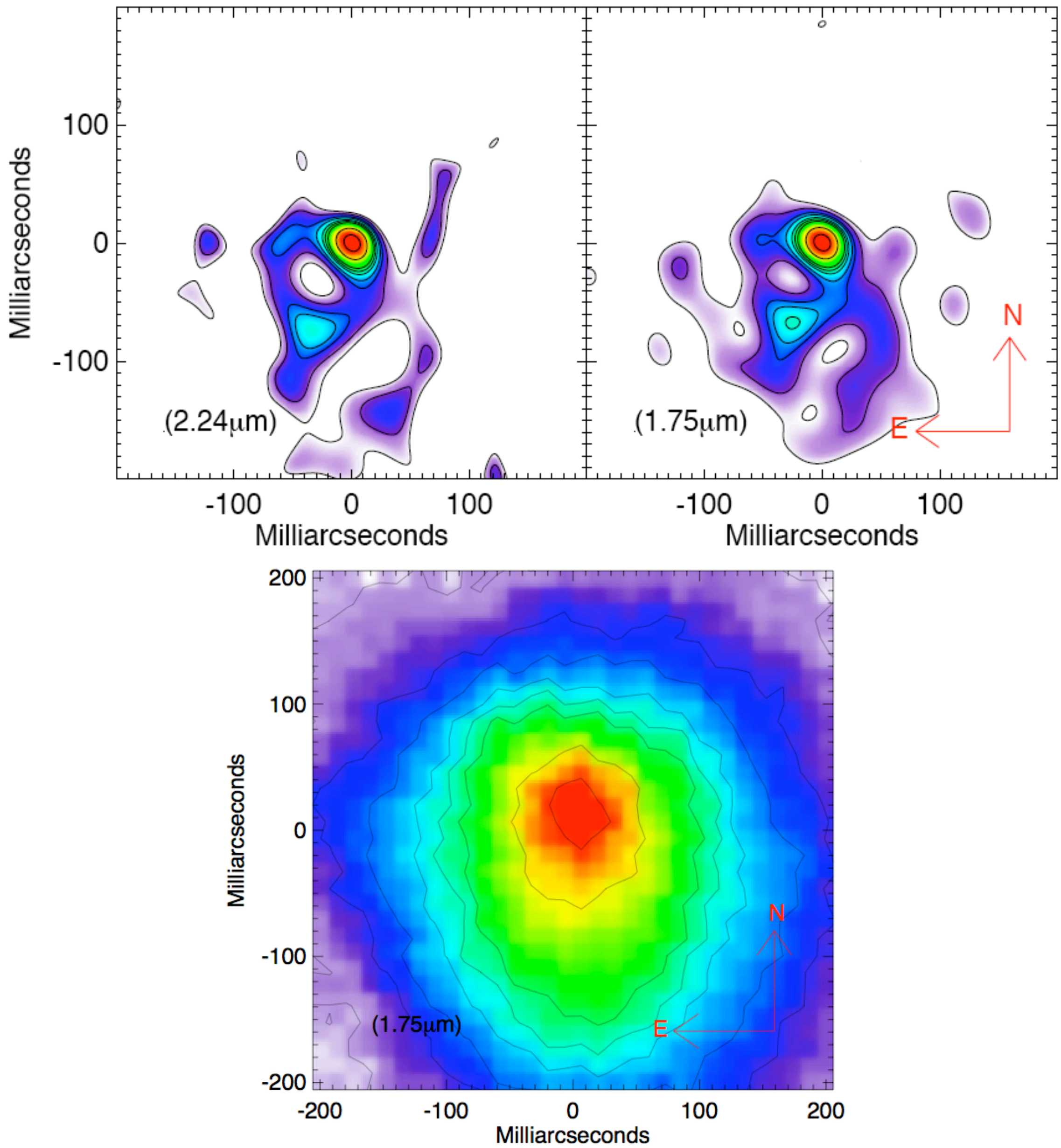


Figure 5-16: Canis Majoris images reconstructed from 18-hole masking data (top) and from a set of shift-and-add stacked full pupil AO frames (bottom).

Other examples of scientific results obtained with SAM on sky can be found on the NaCo Web pages: http://www.pl.eso.org/sci/facilities/paranal/instruments/naco/inst/sam.html

5.6.12 Faint companion detection: theory.

At first glance the spread-out diffraction pattern generated by the mask, which scatters light over a large region, seems to act counter to the objective of revealing a faint companion buried in the halo. Although there is no way to tell from the image plane whether a companion may be present or not, the key advantage offered by a mask is that it enforces a very high degree of stability on the optical transfer function of the telescope. This stability can be exploited to recover moderate-to-high dynamic range companions at high spatial resolution.

A Fourier transform of SAM data will reveal a pattern of regular peaks in the frequency plane (see Figure 5-17 right). Each peak in this complex-number array has an amplitude giving a measurement of the contrast (visibility) of the fringes on that specific baseline, and a phase which is a measurement of the position of the fringes. Before they can be used scientifically, the amplitude measurements need to be calibrated for the average atmosphere/telescope transfer function: this is achieved by the process of observing a nearby reference star as mentioned earlier. Atmospheric turbulence notwithstanding, the normalized amplitude of an unresolved point source star should be 1, and the phase 0. Any value different form 1 (amplitude) or 0 (phase) indicates the presence of resolved structures. These properties were used to achieve the image reconstructions discussed in the previous section.

Unfortunately, calibration of the visibility amplitudes is typically not achieved with high precision (performance will vary greatly with conditions but precision better than 5-10% or so cannot be relied upon). Under these circumstances, visibilities add nothing to the faint-companion search and they are discarded. Thus our detection of high contrast companions relies entirely on the phases, or more precisely, on the *Closure Phases*. These are a better observable because they are inherently self-calibrating, are not biased by the seeing, and they obey quasi-Gaussian statistics.

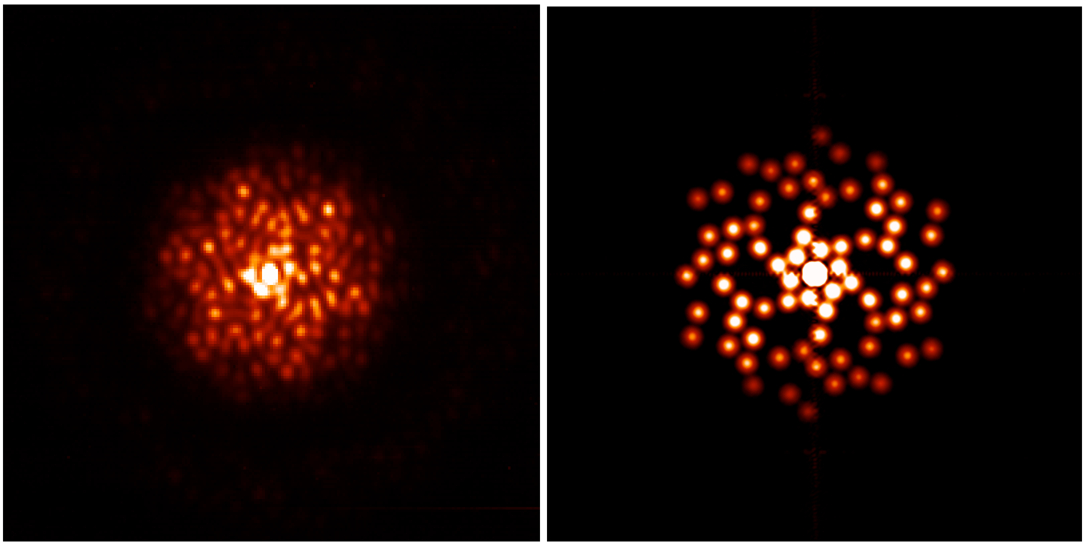


Figure 5-17: (left) image as obtained on the detector observing a calibrator star with the BB_9Holes mask. (right) Fourier transform of this image, revealing peaks corresponding to the different vector baselines passed by the mask.

To give an idea of the behavior of fringe phase for binary star systems, Figure 5-18 represents the phases as a function of the baseline in the mask. This series of plots was drawn for binary systems with 3 different flux ratios, and 3 different angular separations (for a grid of 9 plots). The maximum baseline available with a mask is 8m, while the minimum is the smallest distance between two holes (e.g. 1.17m for the BB_9Holes mask). As can be seen, the dynamic range of the instrument for faint companions will be directly proportional to the precision with which the phases are measured. To achieve a dynamic range of 100, we need phases with a precision of one degree. To achieve a dynamic range of 10 000, we need phase knowledge to be around 0.01 degree.

For high contrast companion detection our goal is simple: extract the phases to fit a binary model as shown in Figure 5-18. There are several ways to do so; here we give one example. The data needed are: the science target data (data cube) and a bad pixel mask and a flat field. We also need to know the effective wavelength λ, the diameter of the holes d and the baselines u.

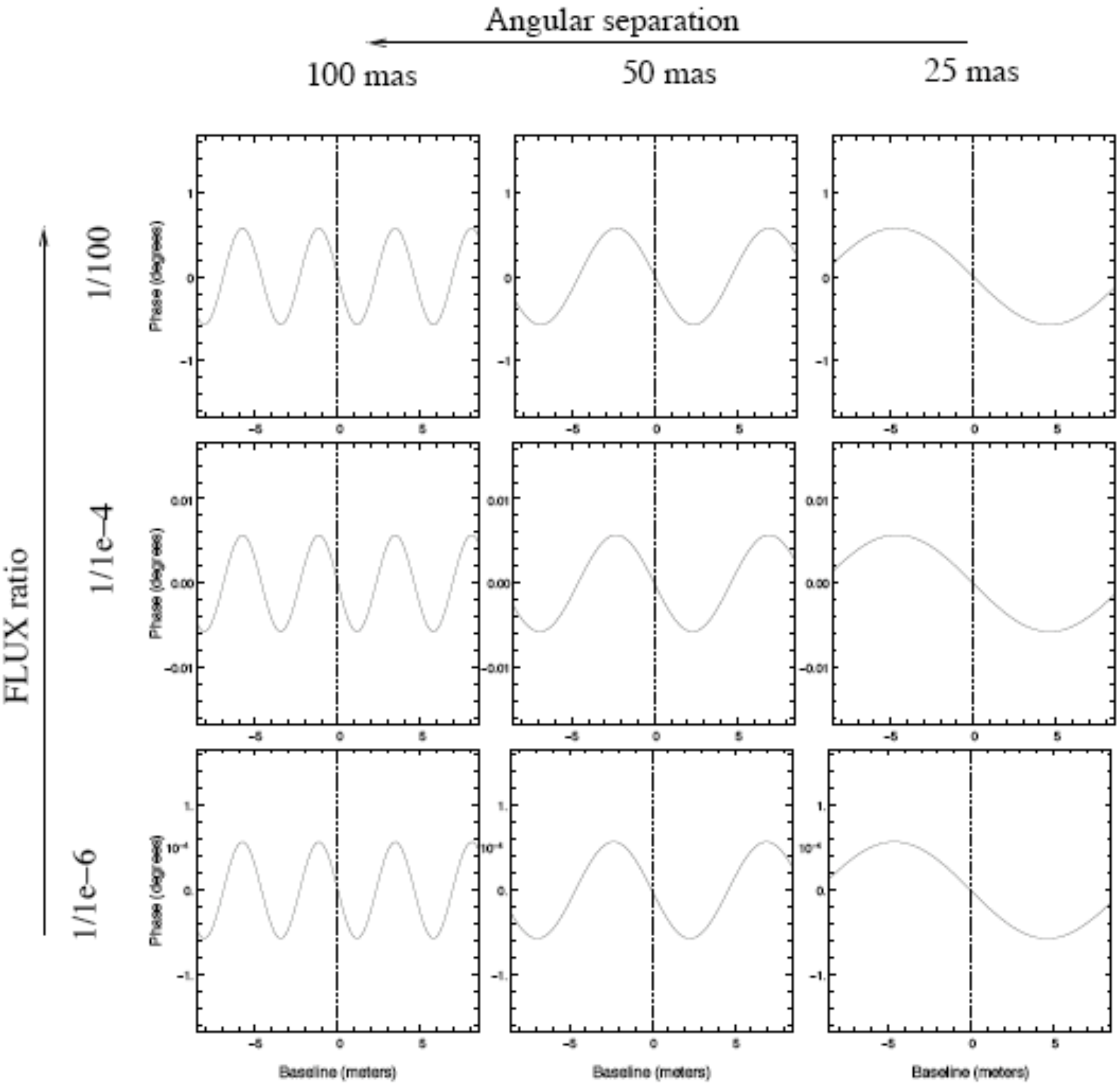


Figure 5-18: Models of fringe phase as a function of the baseline length. A binary system generates phases with a sinusoidal pattern, whose amplitude corresponds to the brightness ratio between the primary and the secondary, while the frequency is proportional to the angular separation.

The data reduction steps are:

1. Flat-field the data.
2. Select a 80×80 pixel zone around the PSF (could be more depending on the size of the PSF. An example is shown in the left panel of Figure 5-19.
3. Fit a model of fringes to each image of the cube separately. The frequency of the fringes should be u/λ_s, with an apodization equivalent to the diffraction figure of a single hole (an Airy pattern of size λ /d. See the middle panel of Figure 5-19.).
4. Derive from the phase and amplitude of the fringes a complex value for each frequency u.
5. From these values derive the bispectrum, and co-add it over all the frames.
6. Take the phase of the bispectrum to obtain the closure phase, eventually de-biased from photon noise.

7. Retrieve the phase of the object from the closure phase and fit with binary model.

5.6.13 On-sky observations: BD-21 4300

BD-21 4300 is a close unequal binary observed in March 2008. One wavelength dataset consists of 4 batches of 60 images of 1.5 sec integration time each (ie. a total integration time of 6 minutes). It was observed with the H and K broad band filters and with the BB_9holes mask. Seeing was average, between 0.8 to 1 arcsec.

Figure 5-19 illustrates the process of fringe fitting. The left panel is a single CONICA exposure, the middle panel gives the best-fit model image, while the right pane is the residual. We derived the closure phases of the object with the method mentioned in section 5.6.12, and fitted these data with a binary star model. The free parameters are the position of companion, the flux ratio, and a piston for each sub-aperture.

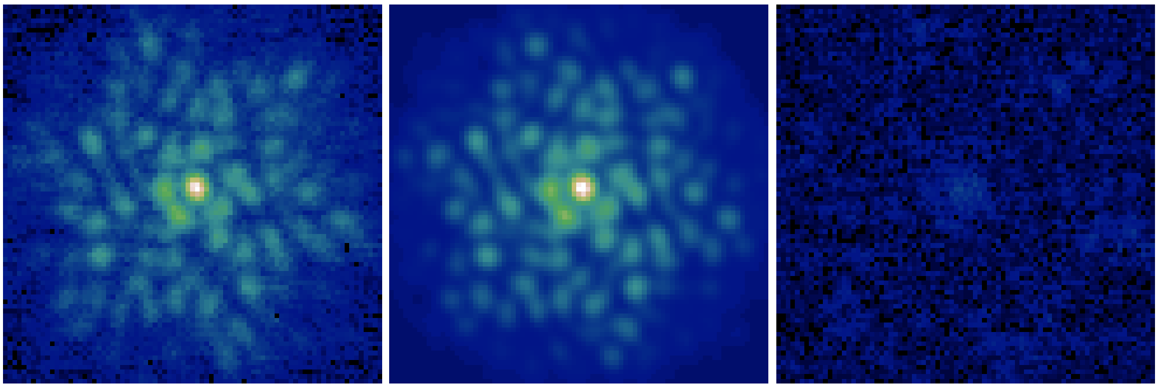


Figure 5-19: Left : CONICA image of a binary star. Center : best fit artificial fringe pattern giving the Fourier amplitudes and phases. Right: the fitting residual shows the discrepancy between data and model.

The parameter space which must be searched for the position of the companion is not necessarily convex, i.e. several minima in χ^2 may exist. Therefore, it is necessary to start with a grid search of the entire space before refining the best fit with gradient-descent. The resulting χ^2 maps are shown in Figure 5-20.

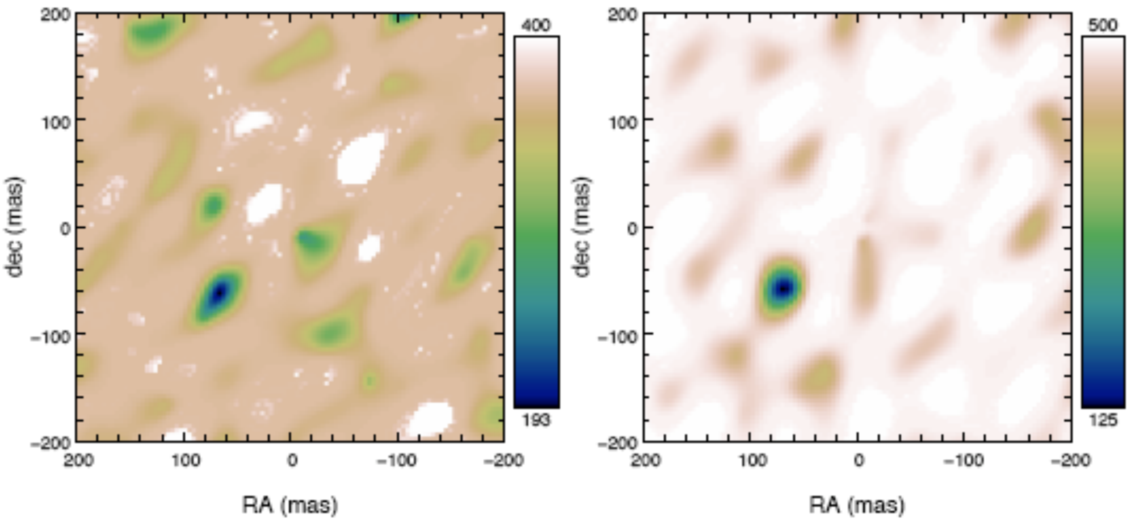


Figure 5-20: χ^2 maps showing detection of the binary BD-21 4300. Left: H band data. Right: K band data. The general χ^2 minimum is at the same position on the two maps.

A clear minimum appears both in the H and K bands. However, note that several other local minima exist. The best fitting result at the global minimum is plotted in Figure 5-21.

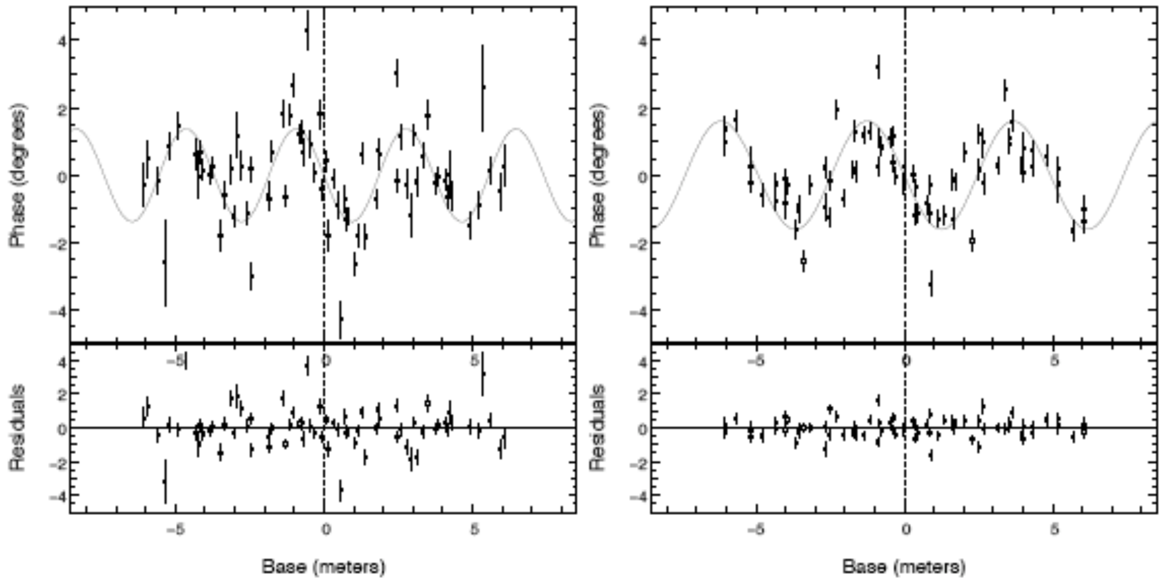


Figure 5-21: Phases measurement for BD-21 4300 as a function of the baseline length. The solid curve is the best fit of a model of a binary star (as presented in Figure 5-18). Right panel: H band data. Left panel: K band data. The companion position and flux ratio are reported in Table 5-13.

Errors on the phases are on average around 0.5 deg in the K band and around 1 deg in the H band. Parameters for the best-fit detection are presented in Table 5-13. The contrast and separation of this companion (4 magnitudes and 90 mas) agree well with the original detection of this companion at Keck (Kraus et al. 2008, arXiv :0801.2387). This companion lies far beyond the detection limit of direct imaging with or without AO.

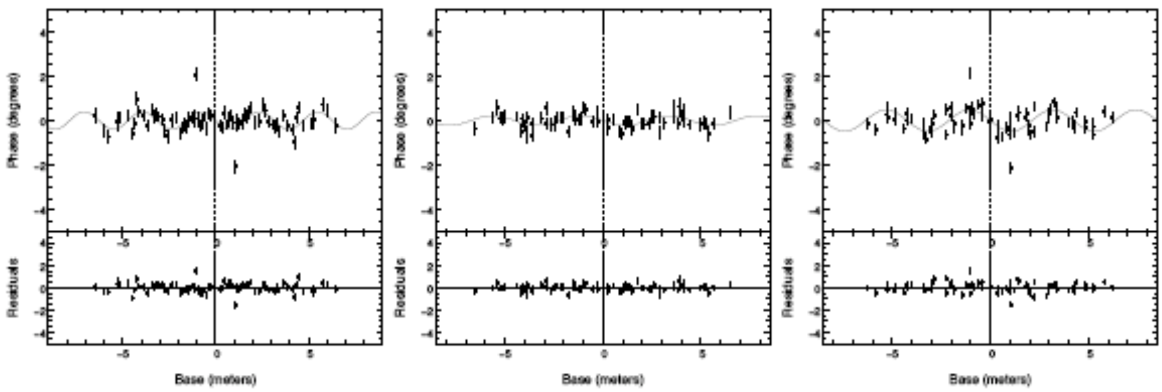


Figure 5-22 Same as Figure 5-21 but using a point-source reference star observed in different filters and masks. Left: 9 Holes (NB_2.17). Middle: BB9_Holes (NB_2.17). Right: BB9_Holes (Lp). All give statistically null results for the presence of a binary companion, with best-fit limits reported in Table 5-14.

Table 5-13: Results from phase fitting of target BD-21 4300

	K Band	H Band
Flux ratio	2.8 ± 0.3%	2.4 ± 0.5%
Separation	89.8 ± 4.0	91.3 ± 5.5

Table 5-14: False detections on calibrator stars

	9Holes (NB_2.17)	BB_9Holes (NB_2.17)	BB_9Holes (Lp)
Flux ratio	0.7 ± 0.2%	0.4 ± 0.1%	0.8 ± 0.3%
Separation	152.8 ± 10.4	100.3 ± 12.5	88.3± 7.5

5.6.14 On sky observations AB Dor in H and K

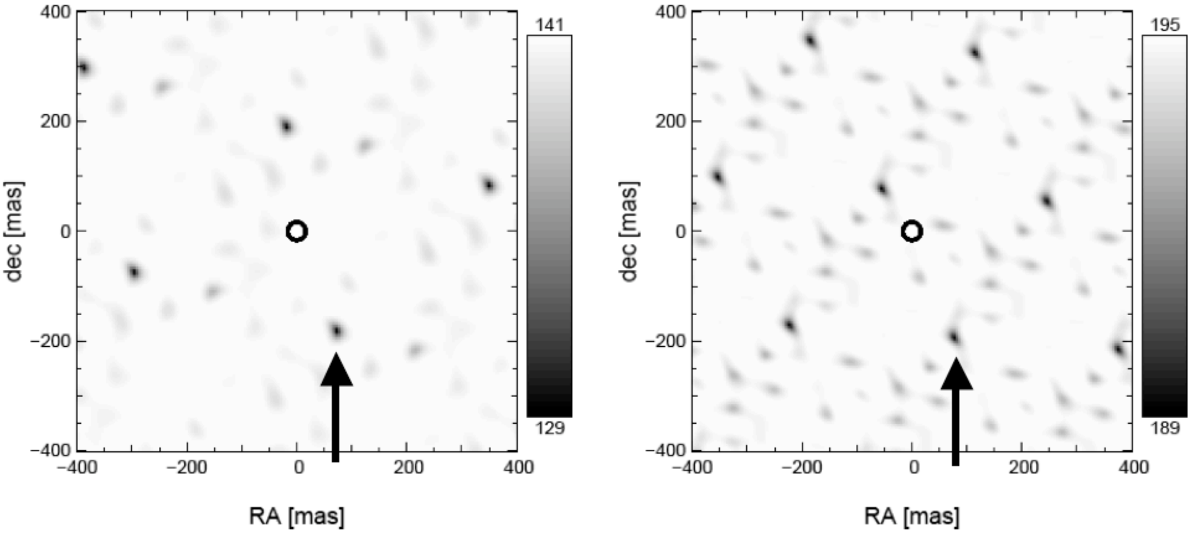


Figure 5-23: Likelihood for the presence of a secondary star as a function of its position. At maximum likelihood, the flux ratio between the main star and its companion is 1.29+/-0.14% in K band (left) and 1.47+/-0.24% in H band (right).

AB Dor was observed between 1h17 and 1h42UT. HD41371 was used for PSF calibration and was observed between 1h54 and 2h12UT. For each one of these targets, the data consist of two data cubes in each band (2.24 μm and 1.75 μm). The cubes are sets of 100 exposures of 2 seconds integration time using a 512×514 windowing of the detector. Seeing was around 1.5", but AO correction was nevertheless stable, with occasional disruptions. The 9 holes mask was used.

Correction for dark, flat-field and bad pixels was applied to our data. An important step was to eliminate exposures where AO correction was unstable. The frequency components (visibilities and closure phases) are then derived. A binary system is fitted to the data, and the likelihood computed.

Figure 5-23 gives the likelihood for the presence of a binary companion as a function of its relative position to the star. A good fit was obtained for several different positions, due to the regular Fourier sampling of the u-v plane. Because the minimum spacing between two holes is 1.73 meters, images are obtained with a modulo $1.73/\lambda$ rad^{-1}. This corresponds to 208 mas in H and 267 mas in K. By using data from the two spectral bands, it is therefore possible to identify the position of the secondary star. The position is indicated by the two arrows in Figure 5-23. Data fitting also allows derivation of the flux ratio between the star and its companion. These results are summarised in Table 5-15:

Table 5-15: result of the observations of AB Dor and its calibrator

Star	**AB Dor**	**AB Dor**
Wavelength	K	H
ΔRA (mas)	-183+/-6	-192+/-9
ΔDec (mas)	75+/-6	77+/-8
Relative flux (%)	1.29+\-0.14	1.47+/-0.24
Delta mag	-4.71+/-0.15	-4.58+/-0.2

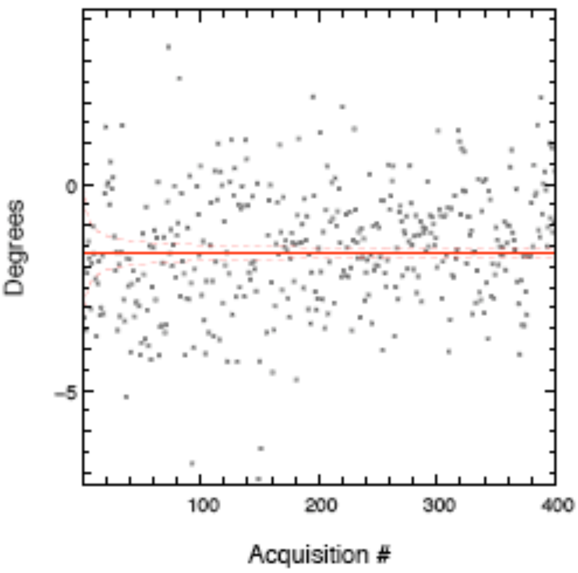
The results on AB Dor are in agreement with the results obtained by coronagraphic means, and with results from the literature (see Janson et al. A&A 462 615 2007). Sources of potential errors are: 1) Uncertainty on the orientation on the field of view on the pupil. Aperture masking requires freezing the spider arms in the pupil plane (vertical mode). The field orientation on the detector is therefore changing with time, which requires further sophistication of the software because the recorded data-header values become inaccurate. 2) Uncertainty on the central wavelength due to the spectral type of the target. 3) Uncertainty on the pupil diameter inside the camera filter wheel. These sources of error at present limit the determination of the relative positions to a few percent – a value that should improve with further characterization.

5.6.15 Additional considerations for faint companion detection

1) **What is the best mask to use for faint companions detection?** It depends primarily on the brightness of the source. If the target is faint (mag > 7), the broadband filters should be used. Therefore, the BB_9Holes mask is recommended (or possibly the 9Holes for fractional bandwidths less than 15%). If the target is bright, the 9Holes mask is recommended, a good compromise between Fourier coverage and throughput.

2) **What is the current limit for the dynamic range?** We tested the dynamic range of the two 9 holes masks for two different wavelengths: K and Lp. False detections are represented in Figure 5-22 and results are reported in Table 5-14. This result shows why it is important to have a stringent SNR cutoff of 5σ for detection of binarity. The parameter space being very large, false detection is likely at 1σ. A result of these tests is that we did not reach the 1/500 detection limit that was hoped for. From the data, we are confident we can have 5σ detections with a dynamic range between 100 and 200. The second result is that the principal source of error is a bias in the closure phase signal due to some unknown artefact in the instrument and/or the data reduction. This bias is illustrated in Figure 5-24, which shows closure phases recorded on a given baseline triangle over 400 separate exposures when looking at a point source reference star (which should give zero closure phases everywhere). It is important to note that the mean (red line) does not converge to zero closure phase as more samples are averaged (dashed envelope). Even worse, this bias offset from the true value (zero) can change as the experimental configuration is moved, as illustrated in the right-hand panel where the same star is observed, but with the interference pattern falling on a different location on the CONICA detector.

3) **What can be done about it?** The bias that can be observed on the phases (see Figure 5-24) does change with the position of the star on the detector. This is why it is difficult to calibrate with a reference star. We are presently investigating the source of this bias and some possible strategies to mitigate it. It may be worthwhile to attempt to put the science and calibrator star at an identical location on the detector. Furthermore, a strategy which consists of multiple visits between the science target and a calibrator spanning an interval of several hours may also help to get rid of some of this systematic error.



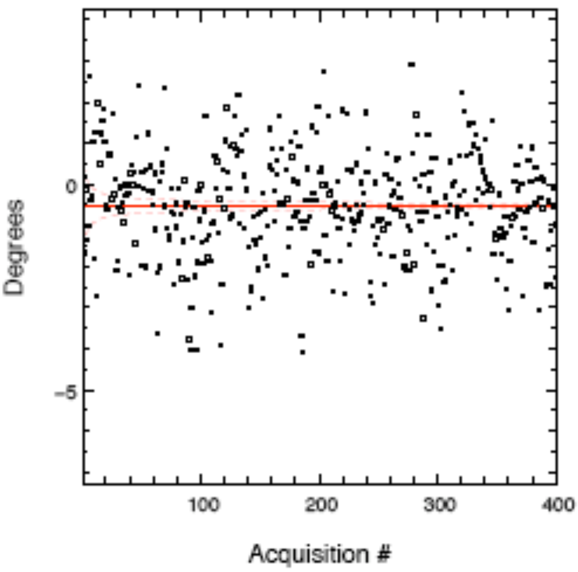


Figure 5-24: Example of strong systematic effect on the phases. Both dataset consists in 400 0.11 ms exposures. The only different between these two dataset are the position of the star on the detector. In red is plotted the mean phase, as well as its statistical rms. If the phases could be de-biased, potential precision on the phase would be 0.1 deg, allowing detection with dynamic range of 1 000.

5.6.16 Calculating exposure times: throughput and sensitivity for selected filters.

In order to convert from the standard CONICA exposure-times given by the online calculator tool (ETC) into SAM exposure data, only two additional numbers are needed. These are (1) the fraction of the mirror area passed by the mask and (2) the fraction of the total flux that will be found in the brightest pixel.

These numbers have been calibrated using the commissioning data for a subset of the total available filter/mask combinations. For filters that have not been calibrated, it should be fairly simple to extrapolate from these numbers to get reasonably close. Note that these numbers have been taken from limited observations, and some values may not be representative of normal seeing conditions, being biased by small sample statistics. Table 5-16 gives mask areas and peak pixel flux ratios for all mask/filter combinations used in commissioning.

These values have been converted into expected count rates using the throughputs from the online sensitivity calculator, and verified on sky. Figure 5-25, Figure 5-26, Figure 5-27 ad Figure 5-28 give the expected peak throughput for various mask, filter and integration time combinations. The information is organized by the various masks, with each plot applying to a separate mask configuration. The different CONICA narrowband interference filters are indicated with different colored line types. For each mask/filter, the expected peak counts received is given for a range of different exposure times starting with the shortest possible (per subframes) up to 10 second integrations. The chip nonlinear regime begins with the horizontal line near the top, and saturation is at the very top.

Table 5-16: Mask area and peak flux ratios for the used mask/filter combinations

18Holes.	**Total area = 3.9% of pupil**
Filter	**Peak Pixel Flux**
NB_1.75	6.38e-4
IB_2.24	6.10e-4
NB_3.74	1.12e-3
NB_4.05	1.26e-3
9Holes.	**Total area = 12.1% of pupil**
Filter	**Peak Pixel Flux**
NB_1.75	1.53e-3
IB_2.24	1.18e-3
NB_3.74	4.42e-3
NB_4.05	4.75e-3
BB_9Holes.	**Total area = 8.7% of pupil**
Filter	**Peak Pixel Flux**
H	1.53e-3
Ks	1.37e-3
L'	2.95e-3
M'	2.72e-3
7Holes.	**Total area = 16% of pupil**
Filter	**Peak Pixel Flux**
H	2.67e-3
Ks	2.53e-3
L'	5.52e-3
M'	** use L'value **

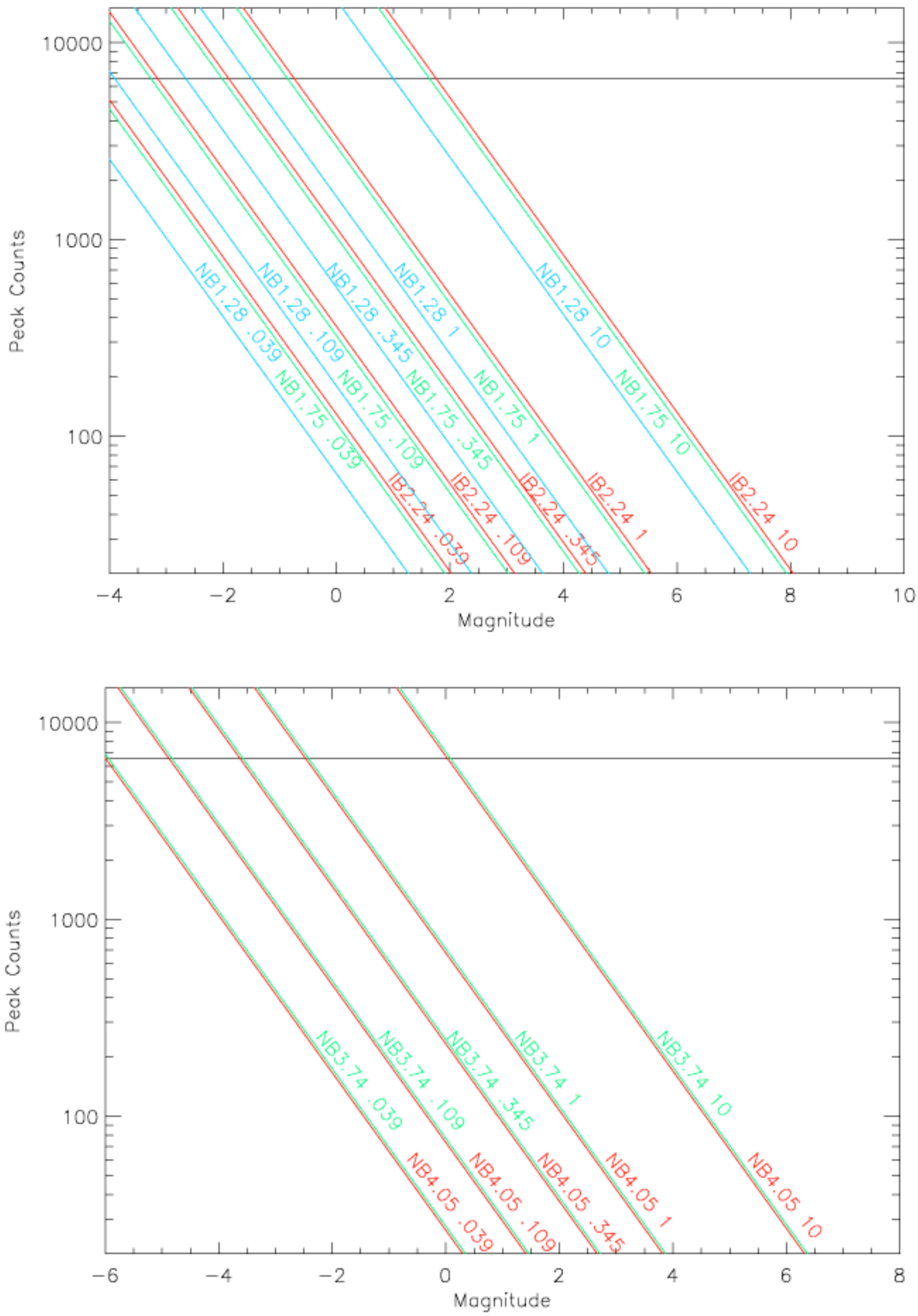


Figure 5-25: Throughput for the 18-Holes mask. Left panel shows throughput with three narrowband filters in J, H and K bands respectively, while the longer wavelengths are given to the right panel. Various integration times are shown (annotated on the plot).

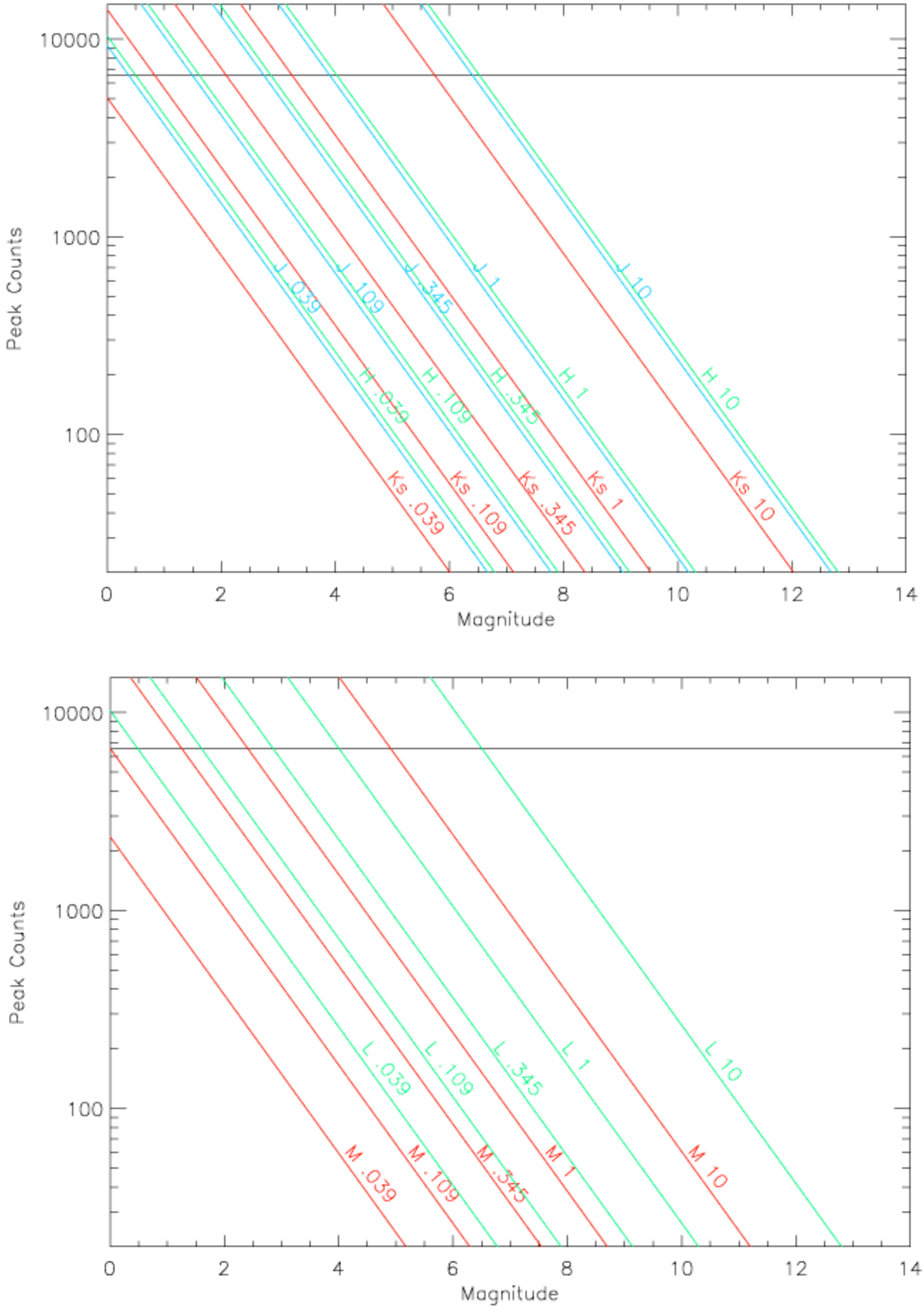


Figure 5-26: Same as Figure 5-25 but for the 9-Holes mask.

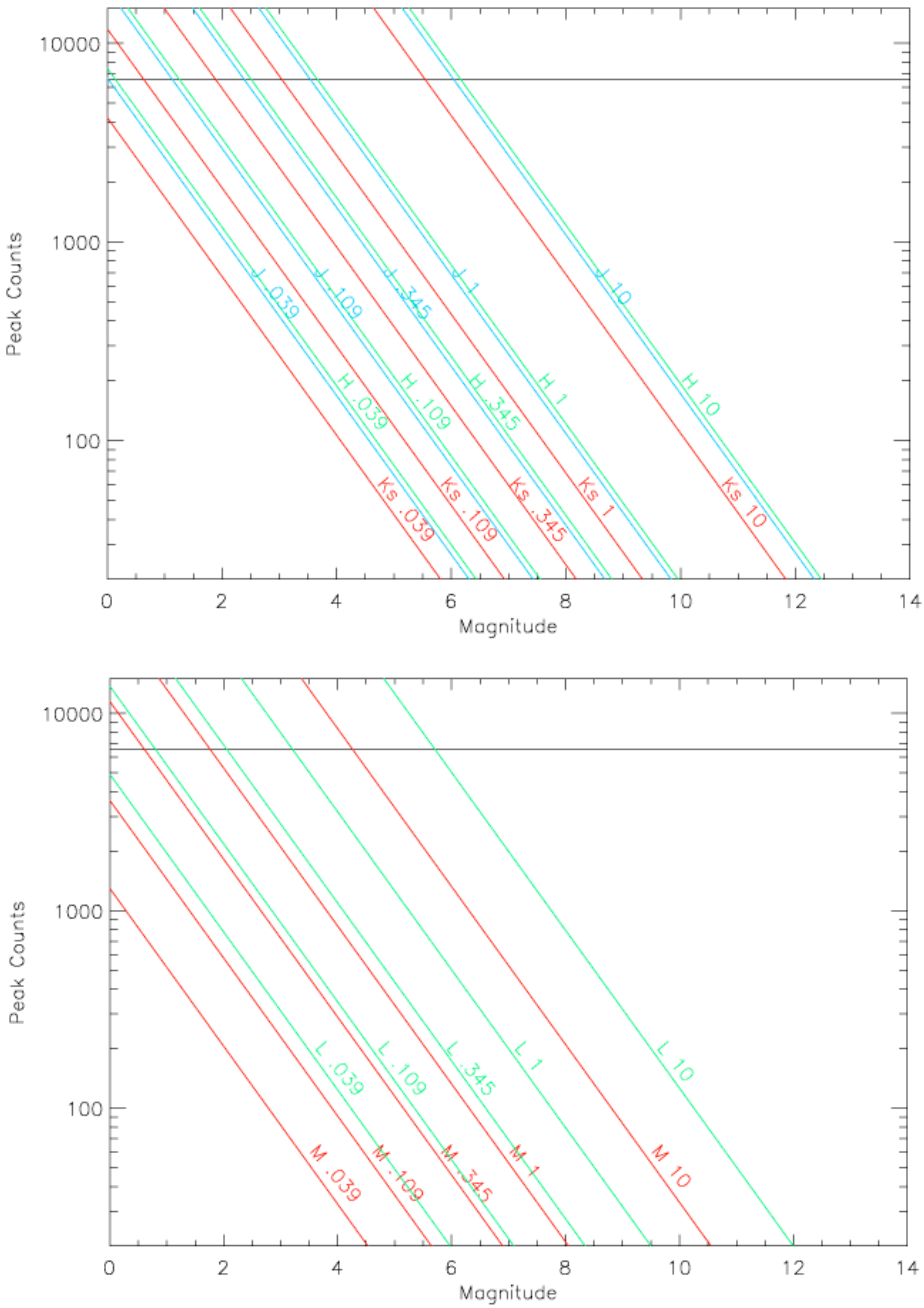


Figure 5-27: Same as Figure 5-25 but for the BB 9-Holes mask

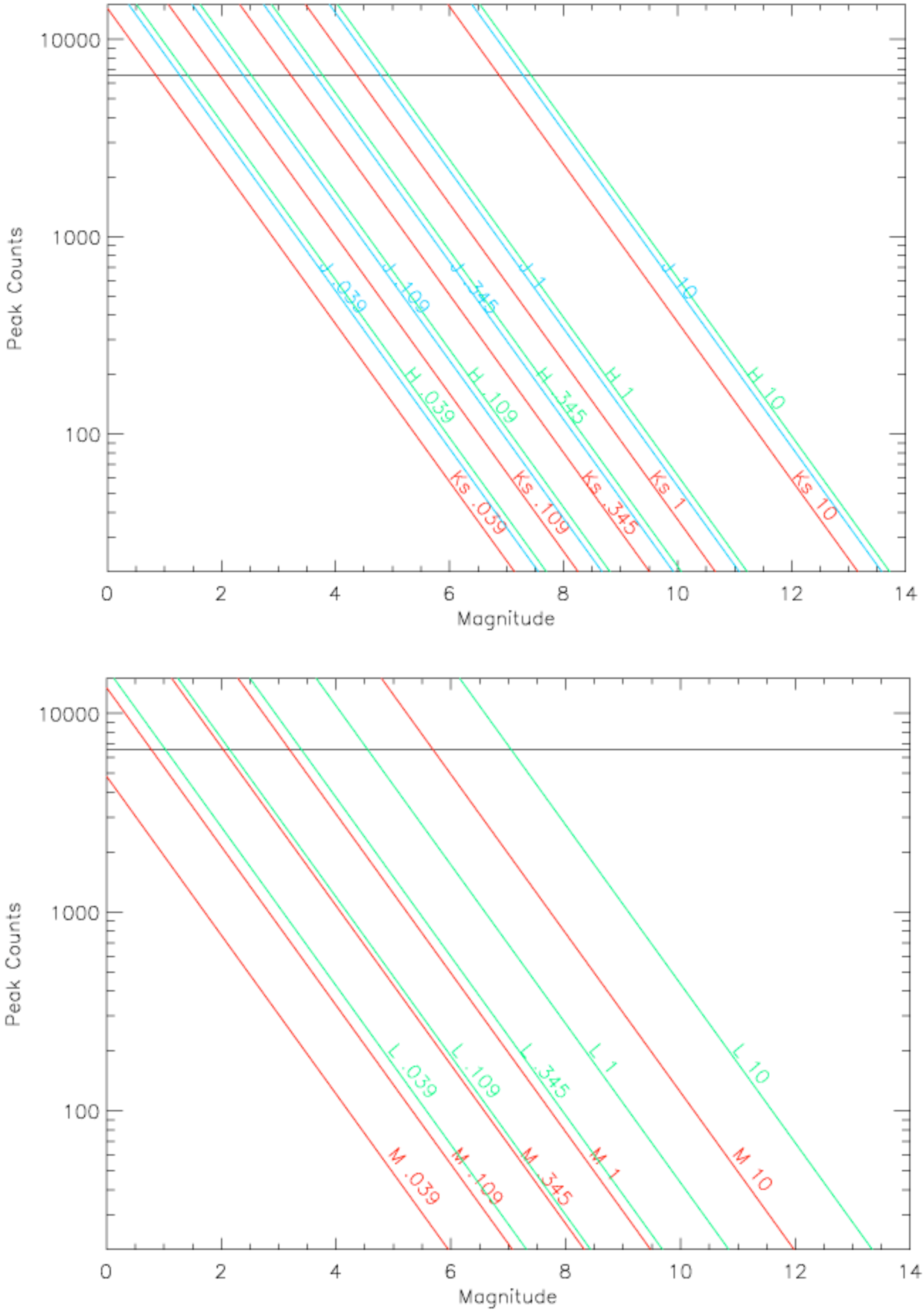


Figure 5-28: Same as Figure 5-25 but for the 7-Holes mask

5.6.17 PSF and MTF

Information on PSF and MTF can be found in the NaCo-SAM web pages: http://www.eso.org/sci/facilities/paranal/instruments/naco/inst/sam.html

5.6.18 Calibration plan for SAM

- Twilight flats as described in section 5.1.3 and internal flats without the masks.
- Detector darks in all readout modes and DITs.

5.6.19 Pipeline for SAM

SAM is not supported by the pipeline.

5.7 CONICA detector

5.7.1 General characteristics

The CONICA detector is a Santa Barbara Research Center (SBRC) InSb Aladdin 3 array. It was installed into CONICA during May 2004 and it replaces the Aladdin 2 detector that had been used since the instrument was first offered. The main characteristics of the Aladdin 3 array are summarized in Table 5-17:

Table 5-17: CONICA detector characteristics

Detector	**Format**	**Pixel Size [μm]**	**Dark Current[1] [ADUs^{-1} pixel^{-1}]**	**Wavelength range [μm]**	**Q.E.**
Aladdin 3	1026[2]×1024	27	0.05-0.15	0.8-5.5	0.8-0.9

The new detector is more sensitive to heavily saturated sources. The limiting magnitudes, that are observable, are specified in Table 6-4. Please check carefully section 6.15 for tolerated "saturated" observations.

For bright objects, a number of electronic and optical ghosts become apparent. If the source is at pixel coordinates (x,y), there will electronic ghosts at approximately (1024-x,y), (1024-x,1024-y) and (x,1024-y) and there may be an optical ghost which looks like a set of concentric rings. The ghosts can be seen in Figure 5-29.

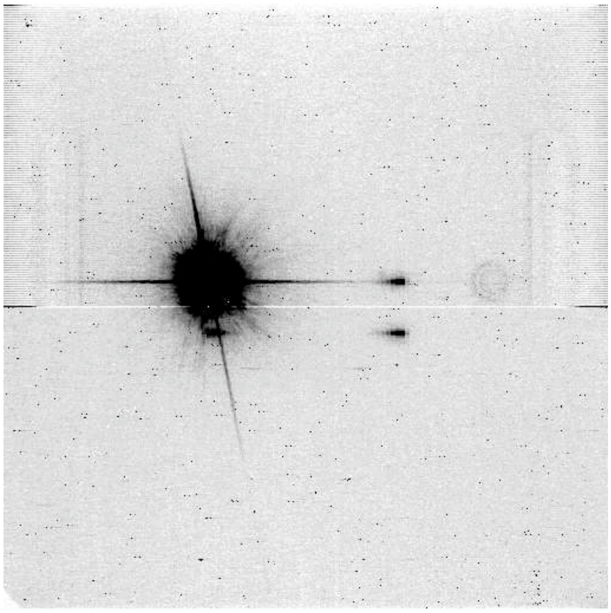


Figure 5-29: Illustration of the ghosts present on CONICA images when observing a bright object. In addition to the electronic ghosts, there is also an optical ghost characterised by its circular shape. The electronic noise visible on the sides of the array, as well as the 'bias' level of rows 512 & 512, disappear in the background subtraction.

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[1] The dark current consists of the array dark current, which is much lower than the numbers listed here, and thermal radiation from the instrument.

[2] Although the array has 1026 rows, only the first 1024 are used. The last two rows do not contain useful data. In most cases, the exception being the cube mode images and Mp imaging frames, users will receive images that have 1024 pixels in x and y. For observations in the Mp, the array is windowed to 512 × 514.

5.7.2 DIT and NDIT

The IRACE controller controls the detector front-end electronics and manages pre-processing of the data before transferring them to the workstation. A single integration corresponds to DIT (Detector Integration Time) seconds. The pre-processor averages NDIT of these before transferring the result to disk. Note that the number of counts in the images always corresponds to DIT, not to the total integration time (i.e. DIT × NDIT).

5.7.3 Readout Modes and Detector Modes

The readout mode refers to the way the array is read out. We offer three readout modes:

- **Uncorr** - The array is reset and then read once. It is used for situations when the background is high, e.g. LW imaging. The minimum DIT without windowing is 0.1750 seconds. For observations in Mp, the array is windowed to 512x514 and the minimum DIT is 0.0558 seconds
- **Double_RdRstRd** - The array is read, reset and read again. It is used for situations when the background is intermediate between high and low, such as SW imaging or LW spectroscopy. The minimum DIT is 0.3454 seconds.
- **FowlerNsamp** - The array is reset, read four times at the beginning of the integration ramp and four times again at the end of the integration ramp. Each time a pixel is addressed, it is read four times. It is used for situations when the background is low, such as SW spectroscopy or SW NB imaging. The minimum DIT is 1.7927 seconds.

The detector mode refers to the setting of the array bias voltage, and four modes have been defined: HighSensitivity, HighDynamic, HighWellDepth and HighBackground. The well depth and the number of hot pixels are directly related to the detector mode. HighSensitivity has the fewest hot pixels, but it has the smallest well depth. Conversely, HighBackground has the largest well depth but has many more hot pixels. The former is used for long integrations in low background situations, where cosmetic quality and low readout noise are paramount, while the latter is used in high background situations where cosmetic quality is less important.

The detector mode is not a parameter that users can select. It is set automatically and depends on the instrument setup. For example, all observations in FowlerNsamp will use HighSensitivity. Details of how the detector modes are assigned are given in Table 5-18.

Table 5-18: CONICA detector readout modes: for each astronomical use, the mode, Readout Noise (RON), gain, full-well (FW) capacity and minimum DIT (min-DIT) are given.

Instrument mode	Readout mode	Detector Mode	RON [ADU]	Gain [e-/ADU]	Full Well [ADU]	Min-DIT [sec]
SW	FowlerNsamp	HighSensitivity	1.3	12.1	7500	1.7927
SW	Double_RdRstRd	HighDynamic	4.2	11.0	15000	0.3454
LW NB imaging	Uncorr	HighDynamic	4.4	11.0	15000	0.1750
LW Lp imaging	Uncorr	HighWellDepth	4.4	9.8	22000	0.1750
LW Mp imaging	Uncorr	HighBackground	4.4	9.0	28000	0.0560

The maximum allowed DIT is now unconstrained by the array. However, in practice, the maximum DIT is defined by the need to get sky frames and this will be around 900 seconds.

Users should be aware that some of the observatory provided calibrations are only done in one readout mode. For example, standard star observations in the SW broad band filters will only be done in Double_RdRstRd.

If users want to observe a standard in a mode that is not supported in the calibration plan, they should submit their own OBs.

Full Well refers to the full well depth. In this case the array is completely saturated and photometry cannot be done. Generally, users should keep the peak count to below two-thirds of the full well depth.

For exposures with DITs that are within a factor of a few of the minimum DIT the well depth is reduced by a factor of approximately two because of the readout overhead.

5.8 Cube mode

Cube mode is a variant of the burst mode already offered with VISIR and ISAAC. In this mode, a data-cube with each single DIT frame is saved. This mode is particularly interesting for lucky-imaging type of observations, where one wants to select the best frames out of a set before co-adding them. The mode can be used for time resolved applications, provided one selects detector setups that do not lose frames and no single DIT frame time stamping is needed. The timing accuracy has been measured in the case of 1-sec sampling frequency. It is believed, but has not been tested yet that the IRACE controller is able to acquire data with microseconds timing accuracy and it is assumed that the additional frame writing overheads are homogeneously distributed dring the exposure time.

There are stringent limitations to the use of the cube mode, in particular it will only be offered in combination with basic imaging, SDI+, coronagraphy and SAM in NGS mode (i.e. no LGS). This mode is only offered for VM runs, even though waivers for simple cases are possible.

Additional advantage of the cube mode is the much smaller overheads needed to save large quantities of frames. When in the past a user would select a certain number of exposures per offset (by means of the NEXP parameter), now one can select cube mode and save all the images in one frame, saving the time needed to save each file (16-17 sec): there is only one readout per cube, which means that hundreds or thousands of frames can be taken with very little overheads.

The size of each cube is limited by the maximum file size accepted by our flavour of Linux, 512 MB. Therefore, given a certain detector window, this fixes the maximum number of planes that can be saved in a cube (i.e. NDIT).

Cube mode is offered in combination with 5 different window sizes. Note that since windowing is done on chip (i.e. hardware windowing), NY=NX+2. Another feature of hardware windowing is that one cannot choose the position of the window within the full frame array: each window is centered on pixel (512,512), and the STARTX and STARTY parameters are fixed by the chosen window size.

Table 5-19 lists the available windows, the minimum DIT and the maximum NDIT for various readout and detector modes. Cube mode is also offered with FowlerNsamp and Uncorrelated read, for NB thermal imaging and Lp without chopping, respectively. Chopping is indeed incompatible with cube mode, since the chopped frames are a different type of cubes by themselves.

The noise characteristics of the cube mode are similar to the normal frames, and temporal noise, i.e. the noise across the cube, is at the same levels of spatial noise. Some extra noise features (fixed pattern 8-pixel noise) appear in the cube frames, especially when very small windows are used.). The cosmetic of the detector is also different, with more blemishes in with smaller windows. These patterns can be eliminated during post-processing of the data.

The overall signal-to-noise in the complete dataset is usually as predicted by the ETC, since the cube mode does not add extra noise, except of course that the readout noise is much more important given the many reads. One can see some additional horizontal additive pattern on the images, not stable between cubes or frames: this pattern can be removed by subtracting the median of each row (M. Durant, private communication)

Random drifts (jitter) in x and y can be seen across the cube. For example, a star can move from one frame of the cube as much as 1-2 pixels, when data are taken with good AO correction. The causes of this jitter are not yet well understood. They represent one more reason why cube mode observations and shift and add post-processing of the images can result in a significant increase of strehl and image quality.

Table 5-19: characteristics of cube mode.

Detector Setup	Window size	Min DIT	Max NDIT[1]	Frame Loss
DCR/HD	1024×1026	0.35	126	5-14%
DCR/HD	1024×1026	0.50	126	0
DCR/HD	512×514	0.109	508	0
DCR/HD	256×258	0.039	2027	0
DCR/HD	128×130	0.016	8049	0
DCR/HD	64×66	0.007	31711	0
Note DCR: minDIT (0.35sec) always loses frames. 0.5 sec does not. Efficient				
FNS/HS	1024×1026	1.793	126	1 frame
FNS/HS	512×514	0.419	508	1 frame
FNS/HS	256×258	0.145	2027	1 frame
FNS/HS	128×130	0.048	8049	1 frame
FNS/HS	64×66	0.014	31711	1 frame
Note FNS: always one frame is lost. Large overheads.				
UCR/HD	1024×1026	0.175	126	~39%
UCR/HD	512×514	0.055	508	~25%
UCR/HD	256×258	0.02	2027	0
UCR/HD	128×130	0.008	8049	0
UCR/HD	64×66	0.004	31711	~21%
Note UCR/HD: for NB thermal imaging only.				
UCR/HWD	1024×1026	0.175	126	~39%
UCR/HWD	1024×1026	0.350	126	0
UCR/HWD	512×514	0.055	508	~28%
UCR/HWD	512 ×514	0.08	508	0
UCR/HWD	256×258	0.02	2027	0
UCR/HWD	128×130	0.008	8049	0
UCR/HWD	64×66	0.004	31711	~21%
UCR/HWD	64×66	0.007	31711	0
Note UCR/HWD for Lp imaging only, no chopping.				

Cube mode overheads for DCR/HD are minimal, given the fact that no readout is performed till the entire cube has been produced. When using min DIT and small windows overheads increase, but are still of the order of few seconds. This is not be the case for FowlerNSampling (FNS) read. This technique inevitably introduces large overheads: for instance, a full frame cube at minDIT needs 8 minutes observtions for 03:45 minutes total

[1] The dimension of the cube will be NAXIS3=NDIT+1. See section 5.10 for details.

exposure time. As a general rule, the smaller the window the higher the overheads, which are ~133% for 512, ~160% for 256, ~250% for 128 greater than ~400% for 64.

5.9 Pupil Tracking (PT) mode

Pupil tracking mode is a new option for imaging applications, 4QPM coronagraphy, classic coronagraphy, SDI+, SDI+4. Pupil tracking mode was implemented to support SAM, but given the demand from the community, it is now offered. In this mode, the telescope, independently from NaCo, tracks the pupil instead of the field. This new tracking mode opens the possibility to do Angular Differential Imaging (ADI), a high contrast imaging technique that reduces quasi-static speckle noise and facilitates the detection of early companions.

Pupil tracking is set during acquisition of the target. The users have only to specify in their template the need for pupil tracking (set the flag to T) and the position angle at which they wish the telescope spiders to be set. Once set in the acquisition, pupil tracking will be "left on" for the duration of the science. For observations requiring a calibrator it is also possible to specify that the spiders keep the same orientation on sky as for the science. In this case the PSF flag in the acquisition template for the calibrator has to be set to T.

The orientation of the spiders is illustrated in Figure 5-30.

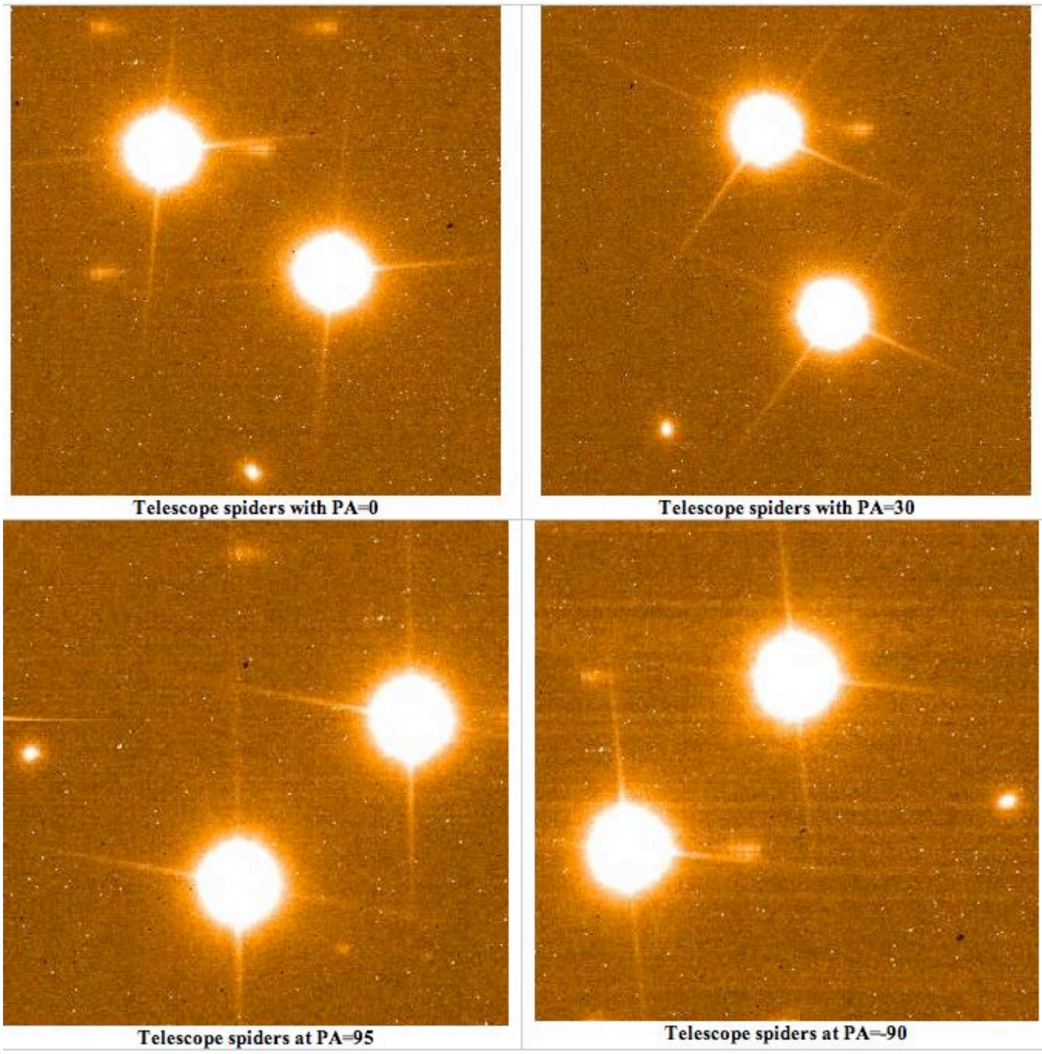


Figure 5-30: Orientation of the telescope spiders for different position angles. The spiders have 180 degrees symmetry, i.e. 90 and -90 look identitical. Spiders rotate clockwise for positive angles.

The spiders angle can be set in the acquisition template by means of the parameter *position angle,* the same used to set the orientation on the sky field-tracking mode. A positive angle rotates the spiders clockwise.

During pupil tracking, the field will rotate around the AO reference at a speed that depends on the object coordinates. Targets close to zenith and passing meridian rotate the fastest.

Given its complexity and novelty, pupil tracking is only offered in VM.

5.10 NaCo data format

With the introduction of the cube mode NaCo will have two different types of data formats, single frames and data cubes.

Single frames are 2-D FITS files (i.e. NAXIS=2) comprised of 1 image and 3 FITS extensions, namely the Modal Voltage COvariance matrix (MVCO), the residual (Modal) Slope COvariance matrix (MSCO) and the Zernike Noise VAriance vector (ZNVA). The extensions store data produced by the NAOS RTC that can be used for PSF reconstruction. The typical image will be a 1024 square array (i.e. NAXIS1 and NAXIS2=1024), when the array is not windowed. The two covariance matrices have dimensions 159×160 or 42×43, depending whether the WFS used the 14×14 or the 7×7 subapertures. The variance vector has dimension 35.

Datacubes are 3-D FITS files (i.e. NAXIS=3), a cube plus the same 3 FITS extensions. The size of the third axis (NAXIS3) is equal to NDIT+1: NDIT is the number of saved DIT frames, and the additional frame at the end of the cube is the combined image, i.e. the frame obtained as a sum of all DIT planes divided by NDIT. This last plane in the cube is the equivalent 2-D image one would obtain in "single frame" mode. The combined image is used for sanity check and quality control at the observatory. **Users are cautioned to use only the first NDIT frames of each cube for their data reduction.** Note also that the first frame in the cube may suffer from some reset anomaly and should probably be discarded. Cubes have NAXIS2=NAXIS1+2 as a rule.

For example, if one windows the array to half its size and takes NDIT=200, the size of the cube will be (NAXIS1,NAXIS2,NAXIS3)=(512,514,201). The FITS extensions remain unchanged.

Chopping mode saves data in cubes of NAXIS3=2, a cube of two frames corresponding to the two average half cycles frames.

6 OBSERVING WITH CONICA AT THE VLT

As with other ESO instruments, users prepare their observations with P2PP. Acquisitions, observations and calibrations are coded via templates (Section 7) and two or more templates make up an Observing Block (OB). OBs contain all the information necessary for the execution of an observing sequence.

Specific to NAOS-CONICA, the Preparation Software (PS) (See Appendix B) is a key–tool, since it allows one to optimize the adaptive optics configuration and to estimate performance. Both the Exposure Time Calculator (ETC) and P2PP use the output from PS to determine feasibility and to prepare observations. For phase II preparation, the PS must be used.

The ETC can be accessed via the regular web based interface (http://www.eso.org/observing/etc/) or via the HTML file produced by PS. For the former, the ETC now calls the NAOS-PS server itself to retrieve the performance estimate. For phase I preparation, users can use either access route, although we strongly recommend the use of the PS for phase I preparation as well.

At the telescope, OBs are executed by the instrument operator. Both NAOS and CONICA are setup according to the contents of the OB. Note that the NAOS configuration might be further optimized at this time in order to provide better performance.

A Real–Time Display is used to view the output of CONICA and to perform acquisitions, while the wavefront pupil is also displayed.

Daytime calibrations are executed the following morning by observatory staff.

6.1 Visitor Mode (VM) operations

Visitors arrive on Paranal two days ahead of their observing run and receive support from Paranal Science Operations (PSO). Users are requested to read the P2PP and NAOS-CONICA User Manuals before arriving. During the night, users do not have direct interaction with the instrument and the telescope. The instrument operator observes the programs under the supervision of the visiting astronomer.

Visitors should be aware that up to 1 hour of their time can be taken by the observatory to comply with its calibration plan. Typically only 15 minutes are needed. The calibrations usually consist of twilight flat fields and imaging standards. For spectroscopic observations, the observatory automatically takes telluric standards for each setting used. Visitors should think carefully about which telluric standards, fundamental to remove telluric features, should be observed. The observatory staff will help them make the right choice.

Even though Paranal is an excellent site, bad weather or poor and fast seeing can occur. Visitors should come with backup programs, particularly if the targets are in the North, where, on some occasions, the wind can be strong enough to prevent the telescope from pointing in that direction. Visitors should also prepare targets with bright ($V < 10$) reference sources so that telescope time can be effectively used when the turbulence is fast.

6.2 Active Optics versus Adaptive Optics

Active optics is the active control of the primary and secondary mirrors of the telescope. Adaptive optics is the correction of wavefront errors induced by atmospheric turbulence. Although, the instrument can run in closed loop without the active optics system controlling the primary and secondary mirrors, one gets better adaptive optics performance if the active optics system of the telescope is running.

6.3 The influence of the moon

Moonlight does not noticeably increase the background in any of the CONICA modes, so there is no need to request dark or gray time for this reason. However, it is recommended not to observe targets closer than 30º to the moon to avoid problems linked to the telescope guiding/active optics system. The effect is difficult to predict and quantify as it depends on too many parameters. Just changing the guide star often solves the problem. Visitors are encouraged to carefully check their target positions with respect to the Moon at the time of their scheduled observations. Backup targets are recommended whenever possible, and users are encouraged to contact ESO in case of severe conflict (i.e. when the distance to the Moon is smaller than 30º). Visitors can use the tools that are available in http://www.eso.org/observing/support.html (select the link "airmass" which is under "User Support Tools") to help determine the distance between targets and the moon for given dates.

However, the moon may affect the quality of the adaptive optics correction, if the source used for wavefront sensing is fainter than V=16. In these cases, reducing the FLI constraint to approximately 0.7 and increasing the distance to the Moon to approximately 50 degrees is generally adequate. Even here, it is important not to over-specify the constraints, as this reduces the chances of the Observing Block being executed. For wavefront sensing in the IR and for reference sources that are brighter than V=16, the values for Lunar Illumination and Moon Angular Distance in the Constraint Sets of your OBs should be 1.0 and 30, respectively.

6.4 Telescope control

Most interactions with the telescope consist of telescope presets for acquisition, telescope offsets during observations, and M2 chopping for some LW observations. Small offsets (i.e. less than one arc minute) are usually completed in 10 seconds of time or less.

It is important to distinguish between the star that is used by the telescope for active optics and the reference object used by NAOS for wavefront sensing.

The active optics stars are automatically selected by the Telescope Control System, and users do not have to worry about finding them.

The reference object used by NAOS for wavefront sensing, and specified within the PS, is chosen by the astronomer (See Appendix B).

It is quite common to offset the telescope very frequently when observing with NAOS-CONICA, and since there are two stars that are used to control the system (one for active optics and the other for adaptive optics) as well as the scientific target, users have to pay very special attention to the restrictions imposed by the system.

There are essentially two kinds of offsets. The first is an offset that results in the NAOS AO loop being closed at the end of the offset. The second is an offset that results in the NAOS AO loop being opened at the end of the offset. In the first case, the field selector (FS) has to move from where it was when the NAOS AO loop was last closed. In the second case the FS does not move.

The field of view of the FS is a bit less than 2 arcminutes. If the offset sequence is such that the positions at which the loop needs to be closed is outside this region, the observations will fail. It is not possible for the system to know beforehand what offsets it will be asked to perform, so if it encounters an offset command which would move the FS beyond its limits, it will 'politely' refuse. Template parameters, which would lead to that happening, are checked for possible problems during OB verification.

When small telescope offsets are used (less than one arc minute), the telescope keeps the same active optics star. If, however, large telescope offsets are used (several arcminutes), the active optics star changes. Nevertheless, when returning to the science target and closing the AO loop on the same reference source, any offsets that might be caused by changing guide stars should be compensated by NAOS.

6.5 Chopping and Counter-Chopping

For coronagraphic observations with the LW filters and imaging and polarimetric observations with the Mp filter, chopping is the only offered mode. For imaging and polarimetric observations with the other LW filters (Lp, NB_3.74 and NB_4.05), chopping is optional.

The basic characteristics and definitions of chopping are:

- The chopping throw is the distance between the ON and OFF beams. The maximum chop throw is 20″. Best results are provided for a chop throw of 15″; which is the recommended limit.
- The chopping angle can be defined with reference to the SKY or to the DETECTOR.
- The chopping frequency is automatically defined in the templates and is based on the filter that is being used. It typically varies between 0.1 and 0.2 Hz.
- One chop cycle corresponds to one ON-OFF cycle, i.e. one period of the M2 chopping motion.
- Several chop cycles can be averaged by the pre-processor to deliver one image. This is referred to as the Number of chop cycles and this parameter is automatically set by the templates.
- The detector acquisition system delivers the two half cycle frames (the ON and OFF images averaged over the number of chop cycles) and the subtracted frame (ie ON - OFF). Objects at the ON position appear negative, objects at the OFF position (if within the field of view) appear positive. Only the half cycle frames are saved to disk and sent to the archive. These frames are stored in a cube. The first plane in the cube corresponds to the ON image and the second plane corresponds to the OFF image, and so on.
- Chopping is always associated with nodding in the opposite direction of the chop. The nodding frequency is also automatically defined in the templates.
- DIT and NDIT are not parameters of the LW chopping templates, as they are automatically set to the optimal values imposed by the chopping frequency and saturation levels.

Chopping with NaCo differs from chopping with ISAAC in one fundamental aspect. In order for the loop to be closed for both the ON and OFF beams, the FS in NAOS must move in phase with M2. This technique is called counter chopping.

It is strongly advised not to attempt chopping for fields where the AO reference star does not allow to correct with a frequency of, at least, 100Hz.

Chopping is not compatible with cube mode observations.

6.6 Target acquisition

6.6.1 Imaging

The NACO_img_acq_MoveToPixel template provides interactive tools like dragging arrows to define telescope offsets.

For SDI+ users must use template NACO_acq_img_SDIMoveToPixel.

6.6.2 Spectroscopy

It is mandatory to use the NACO_img_acq_MoveToSlit acquisition template for all spectroscopic OBs and the same slit in both the acquisition and observing templates.

This template provides interactive tools to rotate the field and to centre objects into the selected slit that is overlaid on the Real Time Display (RTD). It can also be used to place two objects in the slit without having to pre-compute the position angle. Instructions for specifying this acquisition procedure at phase II are in Section 7.3.4 These instructions must be strictly adhered to.

6.6.3 Coronagraphy

It is mandatory to use the NACO_img_acq_MoveToMask acquisition template for all coronagraphic OBs and the same mask in both the acquisition and observing templates.

This template provides interactive tools to centre objects behind the selected mask, which is overlaid on the RTD.

6.6.4 SDI+4

It is mandatory to use the NACO_img_acq_SDIMoveToMask acquisition template for all SDI+4 OBs and also use the same setup in both the acquisition and observing templates, with the possible exception of the ND_Short filter, which is used during acquisition of bright stars. This template provides interactive tools to centre objects behind the 4QPM_H mask.

6.6.5 Polarimetry

It is mandatory to use the NACO_img_acq_Polarimetry acquisition template.

6.6.6 SAM

It is mandatory to use NACO_img_acq_SAMMoveToPixel and use the same mask in both the acquisition and the science templates.

6.7 Pre-imaging

Pre-imaging is offered for programs where critical conditions need to be checked to guarantee the successful execution of the science program. This mode ensures a quick delivery of the data to the user and is restricted to:

- programs that have already requested a separate pre-imaging Run, or otherwise indicated an amount of time to be used for pre-imaging. Examples of cases that may require pre-imaging are programs needing to check either the field orientation (because of possible contamination by a close-by bright star), or the possible binarity of potential targets for occultations, or to refine the slit position in a crowded field.
- 2 imaging templates: NACO_img_obs_AutoJitter and NACO_img_obs_GenericOffset.

For these 2 templates, a new user selectable keyword Observation Category has been introduced and should be set to PRE-IMAGE in the above-mentioned cases only. By default this parameter is set to SCIENCE. Failure set this keyword properly will result in delays to process and deliver the pre-imaging data.

6.8 Finding charts, readme files and OB naming conventions

In addition to the general instructions on finding charts and README files that are available at http://www.eso.org/observing/p2pp/ServiceMode.html, the following NaCo requirements apply:

- At least one chart for each observation must be 2' x 2' in size, with additional charts showing more details as appropriate..
- All wavefront reference stars must be clearly marked according to the way they are ordered in the preparation software. They should be marked R1, R2, R3, etc.
- For imaging, the field of view of the selected camera must be drawn.
- For polarimetric and coronagraphic observations, the field of view of the selected camera must be drawn and the object that is to be placed behind the mask (in the case of coronagraphy) or centred in the mask (in the case of polarimetry) should be clearly indicated.
- For long-slit spectroscopy, the slit must be drawn.
- For slitless spectroscopy, a 14 x 14 arcsecond box should be drawn.
- For spectroscopic templates, the reference star used for preliminary slit centring must be identified.
- For PSF reference stars, the OB name must be prefixed with the string PSF_.
- For pre-imaging, the OB name must be prefixed with the string PRE_.
- For PSF observations, which are to be done as pre-imaging, the OB name must begin with PRE_PSF_.
- The magnitude of the brightest object in all fields, including standard stars, must be explicitly given in the README file and indicated on the finding charts.
- For LGS observations, the TTS magnitude and distance from the target must be explicitly given in the README file and indicated on the finding charts.

6.9 Reference sources for wavefront sensing

The brighter the reference source is and the closer it is to the science target, the better the correction will be.

It can even be the science target itself if it is sufficiently bright and point like.

Whenever possible, several reference sources should be chosen in order to avoid acquisition problems due to binarity, faintness or proper motion of the reference source. The Guide Star and 2MASS catalogues can be used to find suitable references. However for LGS observations, to ease the (development of) operations, the user is restricted to a single Tip-Tilt Star per LGS OB, at least for P83.

In general, the visual WFS will be used, as this ensures that the largest fraction of IR light enters the science channel. The IR WFS should be used for very red sources ($V-K \geq 6$ mag), which could otherwise not be observed with NAOS-CONICA, or for which the IR WFS provides a better correction.

6.10 Strehl Ratio and classification of OBs in Service mode (SM)

To help the observatory determine whether or not an OB has been successfully executed in service mode, the Strehl Ratio of the reference source will be measured with the NB_2.17 filter during acquisition. The measurement during the acquisition process is automatic. Users do not have to worry about it. Depending on the morphology and brightness of the target, the service observer will measure the Strehl ratio on the reference source and a preliminary classification will be made. If the reference is extended, too faint or too bright, the measurement will not be made and the OB classification will be based on the performance that is computed by the RTC.

Alternatively the operator will try to measure the SR on the pipeline-reduced images, whenever suitable sources are available.

If the performance of the RTC cannot give a valid estimate (which is the case for "slow" AO modes) and no other measurements is possible the operator will report the seeing as seen by the guide probe, which is more indicative of the actual observing conditions than the DIMM seeing measurement and indicate the values for other parameters of interest, such as the coherence time.

If we believe that we have achieved a Strehl Ratio which is greater than 50% of that requested by the user, we will consider that the OB has been successfully completed (in the event that all other constraints are met satisfactorily).

We are considering a similar classification scheme for the LGS-operation. Check for updates on the NaCo webpages: http://www.eso.org/instruments/naco/news.html.

6.11 PSF reference star

Observations of PSF stars are frequently used in the analysis of AO data. Generally speaking, the instrument set up should not change between the observation of the science target and the PSF reference, the brightness of the two should be similar and atmospheric conditions should be stable. With NaCo, the simplest way of ensuring that the instrument configuration does not change is to ensure that the PSF reference? (T/F) flag in the acquisition template is set to T. When this flag is T, the telescope will preset to the target, the operator will acquire the target and AO will start without changing the NAOS configuration. The time required for PSF reference star observations will be charged to the user.

For service mode observations, we request that all PSF reference OBs are prefixed with the string PSF_ and that clear instructions are written in the README file and the Instrument Comments fields for the science and PSF OBs.

6.12 Recommended DIT and NDITs

Unless the object is bright enough to cause saturation (Table 5-18), DITs need to be somewhat larger than those used in ISAAC, because the NaCo plate scale is considerably finer and it takes longer for exposures to be sky noise limited. However, if there are bright objects of scientific interest in the field of view, then DITs will have to be much smaller than the ones listed in Table 6-1

For DITs larger than 60 seconds, users should consider using FowlerNsamp and not Double_RdRstRd. With DITs larger than 60 seconds, the number of hot pixels in Double_RdRstRd is noticeably larger.

Table 6-1: Recommended DIT and NDIT range

Filter	DIT[sec]	DIT×NDIT [sec]
J, SW NB filters	60-300	120-300
H and Ks	20-120	60-240
LW NB filters	0.175-2.4	40-80
Lp	0.175	30
SW Spectroscopy	60-900	120-900
LW Spectroscopy	0.4-3.0	60-120

These recommendations do not necessarily hold for cube mode, where the choice of DIT and NDIT will depend on the application. For observations that use chopping, DIT and NDIT are computed automatically by the templates.

6.13 IR background

Background is a function of the filter and the dichroic. They are listed in Table 6-2. Users should note that the RON of the array can dominate if DIT is too small.

Table 6-2: IR. Backgrounds. The hyphens mark invalid combinations of a NAOS dichroic + CONICA filter.

Filter	Background magnitude/sq. arcsec				
	VIS	N20C80	N90C10	JHK	K
J	15.8	15.8	15.8	-	5.8
H	14.0	14.0	14.0	-	14.0
Ks	12.8	12.5	11.0	-	-
Lp	3.0	-	-	3.0	-
Mp	-0.5	-	-	-0.5	-

6.14 Recommended magnitude ranges for Standard Stars

The recommended magnitude range for standard stars in imaging and spectroscopy is given in Table 6-3. Saturation with the minimum DIT can occur for targets that are about 1 magnitude brighter than the lower limit in these ranges, but this limit is very sensitive to the level of correction. These magnitude ranges are valid for observations with the visual dichroic. Limits are similar for the JHK and K dichroics and respectively 0.2 and 3 magnitudes brighter for the N20C80 and N90C10 dichroics. For detailed estimates, users should use the ETC.

Table 6-3: Recommended magnitude range of standard stars for observations with the visual dichroic.

Mode	Magnitude Range
SW broad band filters	10-12
SW NB filters	8-10
FP	4-6
LW Lp band	7-9
LW Mp band	6-8
LW NB filters	4-6
SW spectroscopy	6-9
LW spectroscopy	4.5-6

6.15 Maximum brightness of observable targets

Bright targets leave residual images that can take several minutes to disappear. Table 6-4 presents the absolute limits acceptable.

Table 6-4: Magnitude limits for DIT<1 sec

IR Magnitude	Filters to use
> 6	Any
> 4 and <6	Any narrow band filter
> 2 and <4	Any filter plus one neutral density filter.
> 0 and <2	Any narrow band filter plus one neutral density filters.

Please note that the maximum brightness limit is set considering the following limitations:

- The AO acquisition is done on CONICA in imaging mode (i.e with no other dimming optical elements in the path)
- The need to avoid persistence on the CONICA detector.

These limits apply for DIT < 1. Such bright objects heavily saturate the detector and cannot be used for science. For longer DITs, these limits should be increased by approximately 1 magnitude for every 10-fold increase in DIT. The careful reader will note that this is not a linear relation.

When acquiring or when observing targets in imaging or polarimetry, a saturation of a factor 4 is the maximum acceptable. The saturation level is defined for each detector mode by the full well depth (see Table 5-18).

Any other expected saturation level (for field stars) should be accepted prior to observation. In service mode waiver request must be submitted. In visitor mode, prior approval for such observation must be obtained, especially if only half nights are attributed to the project

The magnitude at which saturation starts depends on several parameters (filters, Strehl, objective, etc.). The ETC should be used to check that objects of scientific interest do not saturate the detector. Moreover, actual weather conditions may change this limits. In particular, users are warned that asking for THIN conditions is not a viable strategy, given the variability of the clouds it is too risky to acquire and observe brighter targets that could saturate badly when the conditions change for the best.

Note also that the WFS itself cannot be allowed to saturate, the penalty being the impossibility to perform AO correction. Users need to restrict themselves to the magnitude limits indicated in Table 4-2.

6.16 Nighttime calibrations

For spectroscopic observations, users can take spectroscopic flats and arcs immediately after the observation. These nighttime calibrations are generally better than the ones taken in the daytime, because daytime calibrations are taken with the rotator in a fixed position, and a combination of instrument flexure and in homogeneities along the slit causes the image of the slit on the detector to move by a fraction of pixel when the rotator angle changes.

For coronagraphic observations with the semi-transparent mask, users should take nighttime flats with the NACO_coro_cal_NightCalib template if the flat on/off sequence taken during acquisition is not enough (for C_0.7_sep_10 and 4QPMs only). These nighttime calibrations are significantly better than the ones taken in the daytime, because daytime calibrations are taken without the mask. Daytime calibrations with the mask are not useful, because they are taken with the rotator at a fixed angle, and a combination of irregularities on the glass plate holding the mask and instrument flexure means that flats depend on the rotator angle.

6.17 Instrument and telescope overheads

The execution time report produced by P2PP computes the overheads according to the rules reported in Table 6-5. Users, especially those in service mode, should check them and make sure to take them into account for their Phase 1 (& 2) proposal.

Note that any LGS acquisition will last 10 minutes longer than the corresponding NGS acquisition, i.e. 22 minutes for a polarimetric acquisition using the LGSF.

Some examples are given below to illustrate how to compute overheads with NaCo. In all examples, we have assumed that the reference source used for AO and the target are the same.

Not all parameters of the listed templates are shown. Only those that have an impact on the overheads are listed.

6.18 Observing with the LGS

At the time of updating this manual, the LGS mode of NAOS is still poorly characterised. Its use is for the time being recommended only for science programs that can take advantage of moderate Strehl ratios ("seeing enhancements") to achieve their scientific goals. From the past commissioning experience, one advises to avoid LGS observations for objects with airmass above 1.5, for which the AO correction degrades strongly.

A natural guide star (NGS) is still required to correct for the tip-tilt motions, which are not sensed by the LGS. The NGS has to be in the V magnitude range 12-17 and can be as far away as 40" from the science target, however, with decreasing performance with increasing distance. At 40" distance about half the Strehl ratio is achieved as compared to having the NGS on-axis with the LGS.

It is also important to remember that due to the Cone effect, the maximum Strehl achievable with the LGS is significantly less than the one obtained with a bright natural guide star (20% against 40% in K-band with the AO reference on axis). For information, the LGS is expected to have a magnitude equivalent to that of a star in the range m_V=11-13.

In order to apply for the LGS-mode, just make sure that you have a natural guide star within 40" from your object and that no other mode can be used. It should be stated clearly in the proposal why only this mode can be used and which NGS will be used for tip-tilt sensing.

There are borderline cases when one has to decide whether to select LGS or NGS mode. The limiting magnitude is currently m_V=13.5-14, i.e. with AO reference stars which are fainter than this limit one should select LGS mode and keep the star as a tip tilt reference. Brighter stars offer better performance in NGS mode. When using the PS, a good rule of thumb is the following: if the expected Strehl ratio calculated for the NGS mode is 10% or higher, stay with NGS. Otherwise move to LGS.

Chopping observations are impossible in LGS mode; thus M band observations cannot be performed.

Table 6-5: NaCo Overheads

Acquisition Templates		
Description	**Overhead**	**Comment**
Telescope Preset	3 min	
Guide star acquisition	0.75 min	
Initial setup (NAOS+CONICA)	2 min	
AO acquisition	5-10 min	Depends on the brightness
		of the source used for AO
Strehl measurement	4 min	Not charged to the user
Imaging acquisition	0.5 min	
Polarimetric acquisition	1 min	
Spectroscopic acquisition	1-5 min	Depends on target brightness
Coronagraphic acquisition	2-3 min	Depends on target brightness
SDI+4 acquisition	10 min	Accurate centring is mandatory
LGSF acquisition	10 min	On top of the classical ACQ time
Observation templates		
Readout overhead per DIT (FowlerNsamp)	2 sec	
Readout overhead per DIT × NDIT (Double_RdRstRd)	0.7 sec	
Readout overhead per DIT (Uncorr)	Negligible	
Telescope Offsets	9 sec	1
NAOS header	7 sec	2
Stop and Start AO	2 sec	3
Start and completion overheads for IRACE	9 sec	4
1+2+3+4 = typical offset	27 sec	
2+4 = time between frames without offsets	16 sec	
Change in instrument configuration	1 min	
HWP in (or out)	30 sec	
HWP angle setup	15 sec	
Rotator offset (for polarimetry and SDI)	1-2 min	
Re-centring for 4QPM and SDI+4	2 min	
All observations using chopping	30%	Add to the exposure time
Night time spectroscopic flats	6 min	per on/off pair
Night time spectroscopic arcs	6 min	
Night time coronagraphic flats	6 min	per on/off pair

Table 6-6: Example 1 – Imaging a faint source (V=15 for visual WFS or K=10 for IR WFS) with FowlerNsamp

Template parameters	
Acquisition Template	NACO_img_acq_MoveToPixel
Observation Template	NACO_img_obs_AutoJitter
DIT	3 sec
NDIT	20
Number of offset positions	60
NEXPO per offset position	1
Readout Mode	FowlerNsamp
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	10
Imaging acquisition	0.5
Sub Total (acquisition)	16.25
Observation= 60×(27+20×(3+2))	127
Total [min]	145
Overhaeds	141%

Observation= Number of offset positions×(Offset overhead+NDIT×(DIT+readout overhead))

Table 6-7 – Example 2: Imaging a bright source (V=11 with the VIS WFS or K=7 with the IR WFS) with Double_RdRstRd

Template parameters	
Acquisition Template	NACO_img_acq_MoveToPixel
Observation Template	NACO_img_obs_AutoJitter
DIT	2 sec
NDIT	30
Number of offset positions	20
NEXPO per offset position	3
Readout Mode	Double_RdRstRd
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
Imaging acquisition	0.5
Sub Total (acquisition)	11.25
Observation= 20×(27+2×16+3×(30×2+0.7))	80.3
Total [min]	91.6
Overheads	53%

Observation= Number of offset positions*(Offset overhead+ (NEXPO per offset position-1)*time between frames without offset)+NEXPO per offset position×(DIT×NDIT+readout overhead))

Table 6-8: Example 3: Imaging a bright source in the L band (V=11 for the VIS WFS or K=7 for the IR WFS) with Uncorr

Template parameters	
Acquisition Template	NACO_img_acq_MoveToPixel
Observation Template	NACO_img_obs_AutoJitter
DIT	0.2 sec
NDIT	150
Number of offset positions	120
NEXPO per offset position	1
Readout Mode	Uncorr
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
Imaging acquisition	0.5
Sub Total (acquisition)	11.25
Observation= 120×(27+150×0.2)	114
Total [min]	125
Overheads	108%

Observation= Number of offset positions×(Offset overhead+DIT×NDIT)

Table 6-9 – Example 4: Spectroscopy of faint source with FowlerNsamp

Template parameters	
Acquisition Template	NACO_img_acq_MoveToSlit
Observation Template	NACO_spec_obs_AutoNodOnSlit
DIT	300 sec
NDIT	1
Number of AB or BA cycles	6
NEXPO per offset position	1
Readout Mode	FowlerNsamp
Return to Origin ?	T
Jitter Box Width	10
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	10
Spectroscopic acquisition	5
Through slit	2
Sub Total (acquisition)	22.75
Observation= 2×6×(27+300+2)	65.8
Total [min]	88.6
Overheads	48%

Observation= 2×Number of AB or BA cycles×(Offset overhead+DIT+readout overhead)

Table 6-10: Example 5: SW Polarimetry of bright source with the Wollaston

Template parameters	
Acquisition Template	NACO_img_acq_Polarimetry
Observation Template	NACO_pol_obs_GenericOffset
DIT	10 sec
NDIT	6
Number of offset positions	5
NEXPO per offset position	1
Readout Mode	FowlerNsamp
List of position angle offsets	0 45
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
Polarimetric acquisition	1
Sub Total (acquisition)	11.75
Observations at 0 and 45 degrees = 2×(5×(27+6×(10+2)))	2×8.3=16.4
Rotator offset in between angles	1
Total [min]	23.95
Overheads	193.5%

Observation= Number of offset positions×(Offset overhead+NDIT*(DIT+readout overhead))

Table 6-11 – Example 5b: Polarmetry of bright source with the Wollaston and HWP

Template parameters	
Acquisition Template	NACO_img_acq_Polarimetry
Observation Template	NACO_pol_obs_Retarder
DIT	10
NDIT	6
Number of offset positions	5
NEXPO per offset position	1
Readout Mode	FowlerNsamp
List of HWP offses	0 22.5
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
Setting HWP in/out	1
AO Acquisition	5
Polarimetric acquisition	1
Sub Total (acquisition)	12.75
Observations at 0 and 22.5 degrees= 2×(5×(27+6×(10+2)))	2×8.3=16.4
HWP rotation	0.25
Total [min]	29.6
Overheads	196%

Observation= Number of offset positions×(Offset overhead+NDIT×(DIT+readout overhead))

Table 6-12: Example 6: SW coronagraphy of a bright source with Double_RdRstRd

Template parameters	
Acquisition Template	NACO_img_acq_MoveToMask
Observation Template	NACO_coro_obs_Stare
DIT	10 sec
NDIT for the OBJECT positions	6
NDIT for the SKY positions	5
Number of AB cycles	2
Number of exposures (OBJECT Only)	10
Number of offset positions (SKY only)	4
Readout Mode	Double_RdRstRd
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
Coronagrahic acquisition	2
Sub Total (acquisition)	12.75
Observations= 2×(10×(6×10+0.7)+9×16+27+4×(5×10+0.7+27))	36
Total [min]	49
Overheads	84%

Observation= Number of AB cycles × (Number of exposures (OBJECT)×(DIT×NDIT+readout overhead)+(Number of exposures (OBJECT)-1) × time between frames without offset) + Offset overhead)+Number of offset positions (SKY)×(DIT×NDIT+readout overhead+offset overhead)).

Table 6-13 – Example 7: LW coronagraphy of a bright source

Template parameters	
Acquisition Template	NACO_img_acq_MoveToMask
Observation Template	NACO_coro_obs_AutoChopNod
Integration Time	20 min
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
Coronagraphic acquisition	2
Sub Total (acquisition)	12.75
Observation= 20×(1.3×60+27)	35
Total [min]	48
Overheads	140%

Observation= Integration time (minutes)×((1+30%) × 60 sec + Offset Overhead)

Table 6-14- Example 8: Imaging with chopping

Template parameters	
Acquisition Template	NACO_img_acq_MoveToPixel
Observation Template	NACO_img_obs_AutoChopNod
Integration Time	20 min
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
Imaging acquisition	0.5
Sub Total (acquisition)	11.25
Observation= 20×(1.3×60+27)	35
Total [min	46
Overheads	130%

Observation= Integration time (minutes)×((1+30%) × 60sec + Offset Overhead)

Table 6-15 – Example 9: A bright source with SDI+

Template parameters	
Acquisition Template	NACO_img_acq_SDIMoveToPixel
Observation Template	NACO_sdi_obs_GenericOffset
DIT	10 sec
NDIT	6
Number of offset positions	5
NEXPO per offset position	1
Readout Mode	Double_RdRstRd
List of position angle ffsets	0 33
Return to original rotator postion	F
Execution Time [min]	
Preset	3
Guide Star Acquisition	0.75
Initial Setup	2
AO Acquisition	5
SDI+ acquisition	1
Sub Total (acquisition)	11.75
Observation at 0 and 33 degrees= 2×5×(27+6×10+0.7)	2×7.3=14.6
Rotator Offset	1
Total	27.3
Overheads	173%

Observation= Number of offset positions × (Offset overhead + NDIT × DIT + readout overhead).

7 NAOS-CONICA TEMPLATES

The instrument, detector and telescope are controlled by Observing Blocks (OBs), which are made up of templates. Templates are divided into three categories: acquisition, observation and calibration.

Usually, OBs consist of an acquisition template and one or more observation templates for nighttime observations and, in some limited cases, an additional nighttime calibration template.

Only one acquisition template is allowed in an OB, and therefore only one preset on sky. It is not possible e.g. to group in the same OB observation templates on the science object and calibration template on a standard star. Table 7-1 provides a short summary of the templates offered for P82. These templates should cover most needs. If this is not the case, users must contact the User Support Department (usd-help@eso.org) well before the start of observations.

7.1 General remarks and reminders

Only parameters specific to NaCo are described. The description of other parameters can be found in the P2PP User Manual (http://www.eso.org/observing/p2pp).

- We strongly recommend that you consult the NaCo web pages for the latest information.
- All imaging observations must use the NACO_img_acq_MoveToPixel template for acquisition.
- All polarimetric observations must use NACO_img_acq_Polarimetry for acquisition.
- All spectroscopic observations must use NACO_img_acq_MoveToSlit for acquisition.
- All coronagraphic observations must use NACO_img_acq_MoveToMask for acquisition.
- All observations with the SDI+ must use NACO_img_acq_SDIMoveToPixel for acquisition.
- All observations with the SDI+4 must use NACO_img_acq_SDIMoveToMask for acquisition.
- Al observations with SAM must use NACO_img_acq_SAMMoveToPixel for acquisition.
- It is possible to submit a single OB that comprises several observing descriptions, for example one can observe a single target with different filters, but most mixed mode observations (e.g. coronagraphy with spectroscopy) are generally not allowed. Direct imaging after any other mode is allowed, but users should note that the position of the object in the CONICA FoV will slightly change when moving from either coronagraphy or spectroscopy to imaging, because different flexure compensation models are used for these modes.
- Some targets we are asked to observe saturate the detector with the minimum DIT. Consult the ETC.
- The pixel scale is very small, so the readout noise can dominate if the DIT is too small. Consult the ETC.
- In the NACO_spec_obs_AutoNodOnSlit template, the jitter width should be smaller than the throw.
- Cube mode is a feature that can be turned on for science templates (not acquisition) by means of the flag in the P2PP file. Note that the default window is 1024×1026, and other windows will have different sizes (512, 256, 128 and 64, with NY=NX+2) centred on pixel 512, 512 (i.e. the user cannot set STARTX and STARTY, the lower-left coordinates for the detector window).
- Pupil tracking mode is set in the acquisition template by means of the correspondent flag in P2PP. Note that all the acquisition templates, including the ones for modes that are not offered with pupil tracking, contain this flag.

Table 7-1: NaCo template suite

Action	Template
General to all observing modes	
Turn the field (= telescope rotator)	NACO_all_obs_Rotate
Acquisition Templates	
Preset telescope and acquire for imaging	NACO_img_acq_MoveToPixel
Preset telescope and acquire for SDI+	NACO_img_acq_SDIMoveToPixel
Preset telescope and acquire for polarimetry	NACO_img_acq_Polarimetry
Preset telescope and centre object(s) in the slit	NACO_img_acq_MoveToSlit
Preset telescope and centre object behind a mask	NACO_img_acq_MoveToMask
Preset telescope and centre object in SDI+4	NACO_img_acq_SDIMoveToMask
Preset telescope and acquire for SAM	NACO_img_acq_SAMMoveToPixel
Imaging or SDI+	
Imaging of un-crowded fields	NACO_img_obs_AutoJitter
Imaging of extended objects or crowded fields	NACO_img_obs_GenericOffset or NACO_img_obs_FixedSkyOffset
Imaging requiring special offset sequences	NACO_img_obs_GenericOffset
Imaging with chopping in Lp or Mp	NACO_img_obs_AutoChopNod
Imaging with SDI+	NACO_sdi_obs_GenericOffset
Spectroscopy	
Spectroscopy of point–like or moderately extended objects	NACO_spec_obs_AutoNodOnSlit
Spectroscopy of extended objects (>10″) or complex sequences of positions	NACO_spec_obs_GenericOffset
Polarimetry	
Imaging Polarimetry	NACO_pol_obs_GenericOffset
Polarimetry with the Half Wave Plate	NACO_pol_obs_Retarder
Coronagraphy	
Coronagraphy Coronagraphy+imaging	NACO_coro_obs_Stare NACO_coro_obs_Astro
SDI+4	
4QPM_H coronagraphy + SDI+	NACO_sdi4_obs_Stare
SAM	
SAM (includes Pupil Tracking) observations	NACO_sam_obs_GenericOffset
Standard Stars	
Standard star for imaging Standard star for imaging with chopping Standard star for coronagraphy Standard star for spectroscopy Standard star for polarimetry	NACO_img_cal_StandardStar NACO_img_cal_ChopStandardStar NACO_coro_cal_StandardStar NACO_spec_cal_StandardStar NACO_pol_cal_StandardStar
Night time calibrations	
Night time coronagraphic and SDI+4 flats	NACO_coro_cal_NightCalib
Night time spectroscopic flats and arcs	NACO_spec_cal_NightCalib

- With the exception of standards, the minimum amount of time between exposures is 30 seconds. This limit is set to allow the telescope Active Optics to at least perform one correction.
- Ensure that the correct filters are used when acquiring bright targets for spectroscopy.
- When doing a blind offset from a bright reference object to a faint target, we strongly recommend that the position angle be set so that the reference object and target fall in the slit at the same time. Additionally the coordinates of the reference object are the ones that should go into the OB.
- When using extended objects as AO reference sources, make sure that the flux within the specified aperture is correct. Users tend to significantly overestimate this flux.
- The verify button on P2PP checks that individual parameters are within the defined ranges and some additional checking on the global logic of selected OBs.
- The Strehl, seeing and airmass constraints, as well as the epoch, equinox and RA and DEC (and respective proper motion) fields of P2PP will be automatically filled when the configuration file is loaded. Do not edit these fields.
- There must be one AO configuration file per target. The same AO configuration file cannot be used for different targets.
- Each acquisition, science or calibration template that generates files, writes three header keywords, DPR.CATG, DPR.TYPE and DPR.TECH. These keywords are used by the pipeline, and can be used by the users, to classify files or to make queries in the archive (for example, using the NaCo specific query form at http://archive.eso.org/wdb/wdb/eso/naco/form). The complete list of templates and corresponding DPR keywords is given in Section 10.

7.1.1 Offset conventions and definitions

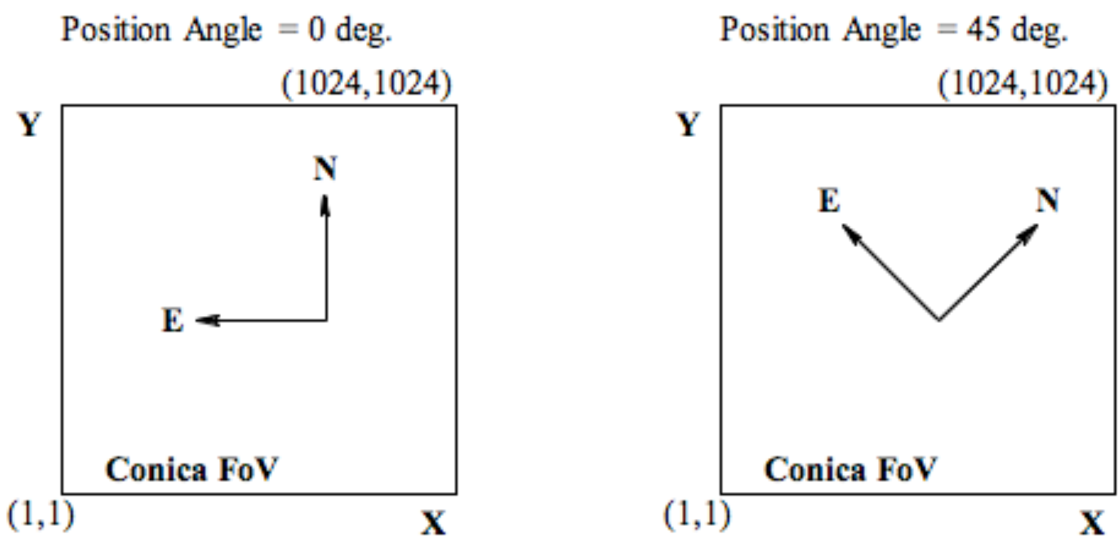


Figure 7-1: Orientation for imaging, polarimetry and coronagraphy. (Left): Field orientation on detector at 0° rotation angle on sky, (Right): Field orientation at +45° rotation angle on sky.

- For imaging, polarimetry and coronagraphy, East is on the left (X−) of the images for zero position angle. For spectroscopic acquisition, East is at the top (Y+) for zero position angle.
- For imaging, polarimetry and coronagraphy, North is at the top (Y+) of the images for a zero position angle. For spectroscopic acquisition, North is on the right (X+) for a zero position angle.

- Position angle on sky. This angle is measured in the standard way, i.e. it is positive from North to East.
- The slits are oriented along detector rows.
- For spectroscopy, a position angle of zero means that the slit is aligned North-South.
- For polarimetry, a position angle of zero means that the mask is aligned East-West.

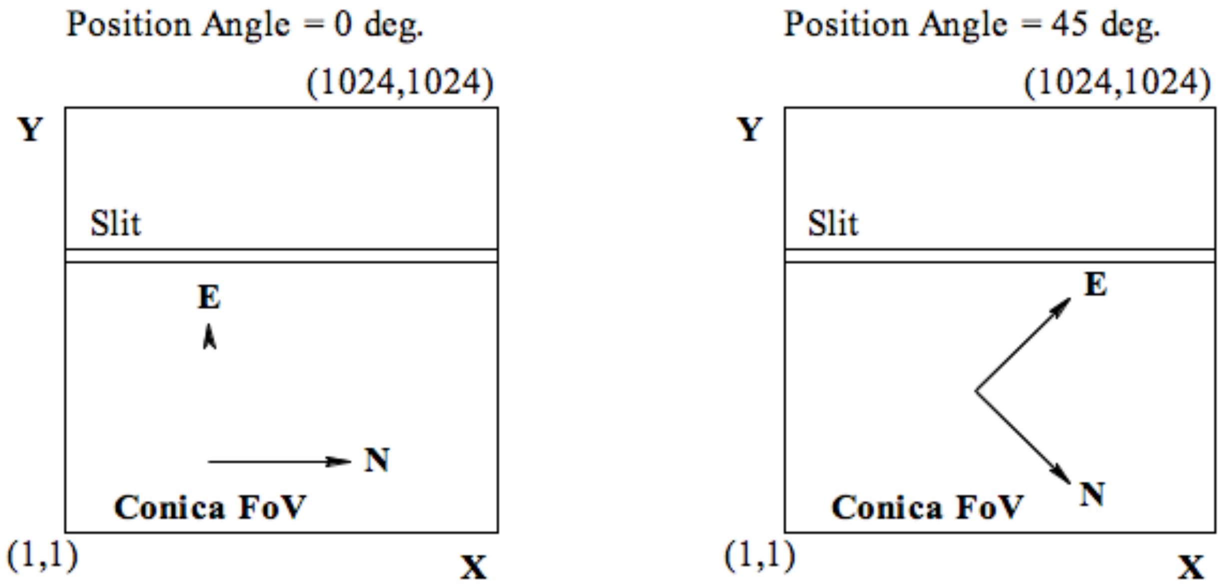


Figure 7-2: Orientation for spectroscopic observations. (Left): Field orientation on detector at 0º rotation angle on sky, (Right): Field orientation at +45º rotation angle on sky.

The templates make extensive use of telescope offsets. In some templates the offsets are set automatically (e.g. NACO_img_obs_AutoJitter), but in others the offsets have to be entered manually as lists. In this latter case, the convention is that offsets are relative. E.g. the following list of offsets

RA offset list (arcsec)	0 10 -10 20 -20
DEC offset list (arcsec)	0 0 0 0 0

will result in a first image without offset, a second image in which the telescope was moved 10 arcsec East, a third image at the original position, etc.

Sometimes, offsets may be defined in detector coordinates. In that case, a positive offset in X will move the image to the right (X+) (the telescope offset is therefore in the opposite direction).

All offsets are defined in arcsec, even the offsets that are defined in detector coordinates. Therefore, an offset of +10 in X will move the object 10″ to the right.

7.2 NaCo General templates

7.2.1 NACO_all_obs_Rotate

The NACO_all_obs_Rotate template rotates the field of view and it has only one parameter - the rotator offset angle. The angle is in degrees and a positive angle will rotate the adaptor from North to East. Hence, objects in an image will rotate from North to West. The angle is relative; hence the position angle of the field at the end of the rotation will be the position angle of the field before the template was run plus the angle in the template. The template can only be followed by imaging templates.

7.3 NaCo Acquisition templates

Telescope presets can only be done via acquisition templates and all observing blocks must start with one. There are seven acquisition templates: one for imaging, and one each for SDI+ imaging, spectroscopy, coronagraphy, SDI+4, polarimetry and SAM. They are listed in Table 7-1.

All acquisition templates preset the telescope to the AO reference star, set up NAOS and CONICA, close the loop and acquire the science target.

All acquisition templates require a NAOS parameter file, (a.k.a. aocfg file), which contains information about the target, the reference source, the NAOS setup and other ancillary data. Once this file is loaded, the target fields in P2PP will contain the target coordinates.

The acquisition templates can take anywhere from one to five images during the acquisition process. See the description of the individual acquisition templates for a description of what kind of images are recorded.

In general, it is not necessary for the acquisition and the subsequent observation templates to have the same DIT and NDIT, nor the same filter, but it is recommended. Exceptions are: SAM, where the mask cannot change from acquisition to science, SDI+4 and the 4QPMs, which, once inserted, are never removed from the optical path.

The detector and readout modes are not parameters of the acquisition templates. They are automatically set and they depend on the filter. For LW filters, the readout mode is set to Uncorr and the detector mode is set to HighDynamic. For all other filters the readout mode is set to Double_RdRstRd and the detector mode is set to HighDynamic. The minimum DITs for these modes are listed in Table 5-18.

For very bright targets a neutral density filter can be inserted into the light path. The choices are: Full for no neutral density filter, ND_Long for a LW neutral density filter and ND_Short for a SW neutral density filter. Filter curves are plotted in Section 8.

All acquisition templates can be used to acquire PSF stars. In such cases, the PSF reference? (T/F) flag should be set to true. Although the NAOS configuration will be ignored during the acquisition, a valid NAOS parameter file is still required. By default, the PSF reference? (T/F) flag is F. Note that this flag, when used with pupil tracking (including SAM) will additionally keep the pupil angle fixed.

As of P82 some acquisition templates have been modified to collect useful calibration data, "free" (i.e at no extra time cost) for the users:

1. NACO_img_acq_MoveToMask, NACO_img_acq_SDIMoveToPixel and NACO_img_acq_SDIMoveToMask: these templates set the instrument in coronagraphic mode, in SDI+ and SDI+4 mode respectively In all cases (except classic Lyot coronagraphy, masks C_0.7 and C_0.14) the setup includes an optical element on glass substrate (thus affected by dust) which does not reposition accurately when it is moves in, out and again in the optical path. Flat fielding used to be difficult because of repositioning problems of the mask elements, unless one opted to use the NACO_coro_NightCalib template at the end of the science observations. The new version of the acquisition templates now acquires one flat on/off pair of images with the element in the same position as used for science. For coronagraphy with classic Lyot elements users can still use the nternal lamp taken during the day or obtain nigt calibrations by means of NACO_coro_NightCalib.

2. NACO_img_acq_MoveToMask and NACO_img_acq_SDIMoveToMask have also been modified to allow taking a PSF image and the relative sky. When the operator elects to take the PSf calibrator, ND filters, if inserted, will be taken off the path, and two images taken: one with the star in the field but at least 2" off the mask and one with no star (i.e. a sky frame).

The files created by these templates are saved together with the acquisition image. They can be recognized by a unique combination of headers keywords:

Table 7-2: keywords combinations used for the new calibration frames.

Image type	**DPR.CATG**	**DPR.TECH**	**DPR.TYPE**	**Note**
Flat on	CALIB	FLAT,LAMP	CORONOGRAPHY or IMAGE, DIFFERENTIAL	INS.LAMP2.CURRENT=value
Flat off	CALIB	FLAT,LAMP	CORONOGRAPHY or IMAGE, DIFFERENTIAL	INS.LAMP2.CURRENT=0
PSF (star)	CALIB	IMAGE	PSF-CALIBRATOR, OBJECT	Optional
PSF (sky)	CALIB	IMAGE	PSF-CALIBRATOR, SKY	Optional

Users are ecncouraged to request the PSF calibrator to be taken by the operator in their README file.

7.3.1 Pupil Tracking (PT) in the acquisition templates

Pupil tracking is started in the acquisition template and it can be set to true only for the templates that support this feature:

NACO_img_acq_SAMMoveToPixel (T by default, angle is fixed)
NACO_img_acq_SDIMoveToPixel (usually F, T is optional)
NACO_img_acq_SDIMoveToMask (usually F, T is optional)
NACO_img_acq_MoveToPixel (usually F, T is optional)
NACO_img_acq_MoveToMask (usually F, T is optional).

In these templates, the rotator angle assumes a different meaning, since the pupil tracking flag has been set to T: it is the angle to which the telescope spiders should be set. In the remaining templates, NACO_img_acq_MoveToSlit and NACO_img_acq_Polarimetry, even though the flag is still present, it must remain set to F. Rotator angle offsets work the same way as in normal rotator mode. A positive angle moves the spiders clockwise. See Figure 5-30 for an illustration.

7.3.2 NACO_img_acq_MoveToPixel

This template does a telescope preset and is followed by interactive centring of the object. It should be used for normal imaging. It must be followed by an imaging template.

Because the objectives are not aligned with respect to each other, we recommend that the acquisition template and subsequent observing templates use the same objective.

In service mode, it is mandatory that users provide detailed information for the field centring on their Finding Charts and/or in their README file.

Table 7-3 describes the parameters of this template.

In order for faint objects to be clearly seen, an image of the sky is acquired in an offset position defined by the RA offset (arcsec) and DEC offset (arcsec) parameters. This image is then subtracted from all images that are subsequently displayed on the RTD. The integration time for these acquisition images is defined by the DIT and NDIT parameters.

This template records an image of the field after the acquisition has been completed. On some occasions, two additional (Br γ) images of the AO reference source, which are used by the operator to help in classifying the OB, are also taken.

Table 7-3: Parameters of NACO_img_acq_MoveToPixel

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	F	Set to true for PT observations
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec)	5	DEC offset for sky image
Position angle on sky	0	Position angle or pupil angle in degrees.
Filter	NODEFAULT	Filter name (e.g. Ks)
Neutral Density Filter	Full	Neutral density Filter (Full=none)
Camera	NODEFAULT	Camera Name (e.g. S27)
NAOS parameter file	NODEFAULT	NAOS aocfg file from JNPS

7.3.3 NACO_img_acq_SDIMoveToPixel

This template is very similar to NACO_img_acq_MoveToPixel (7.3.2) with the exception that the camera and the filter are not parameters of the template. It should only be used to acquire targets for SDI+. The template does a telescope preset and is followed by interactive centring of the object. It must be followed by an SDI+ template.

In service mode, it is mandatory that users provide detailed information for the field centring on their Finding Charts and/or in their README file.

In order for faint objects to be clearly seen, an image of the sky is acquired in an offset position defined by the RA offset (arcsec) and DEC offset (arcsec) parameters. The image is then subtracted from all images that are subsequently displayed on the RTD. The integration time for these acquisition images is defined by the DIT and NDIT parameters.

This template records a flat on and a flat off image, which can be used for flat-fielding the subsequent science frames, two (optional) reference images (star and sky), used by the operator to classify the OB and the final acquisition image with the star centred in the SDI+ field of view.

Table 7-4 describes the parameters of this template.

Table 7-4: Parameters of NACO_img_acq_SDIMoveToPixel

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	F	Set to true for PT observations
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec)	5	DEC offset for sky image
Position angle on sky	0	Position angle or pupil angle in degrees.
Neutral Density Filter	Full	Neutral density Filter (Full=none)
NAOS parameter file	NODEFAULT	NAOS aocfg file from JNPS

7.3.4 NACO_img_acq_MoveToSlit

This template does a telescope preset and is followed by interactive centring of the object in the slit. It is very similar to the NACO_img_acq_MoveToPixel (7.3.2) template; however, it must be followed by a spectroscopic template.

After the AO reference has been acquired, the slit is placed into the beam and an image is recorded. The slit position is computed, the slit is removed and a drawing of the slit is superimposed on the image of the field. The centring of the target is then done interactively.

The template also allows one to place two objects into the slit without the requirement of calculating the position angle beforehand. In such cases, the acquisition strategy should be adequately explained in the README file, and those targets which should be placed in the slit should be clearly designated on the Finding Chart and their position on the slit clearly indicated. To save time during the acquisition, we recommend that users enter an estimate of the position angle into the acquisition template. Table 7-5 describes the parameters of this template.

The "Alpha offset from Ref Star" and "Delta offset from Ref Star" parameters allow the user to define a telescope offset when the acquisition is made on a bright reference object. That is, once the reference object has been acquired and centred in the slit, the offsets defined here will offset the telescope so as to bring the desired target into the slit. Given the accuracy at which the offsets are likely to be defined (the smallest slit is only 86 mas wide so the computed offsets have to be better than a few tens of mas), we do not recommend this option to users. If there is no other option, then the position angle of the slit should be set so that both the reference source and science target are in the slit at the same time.

These offsets should not be confused with the RA offset (arcsec) and DEC offset (arcsec) offsets, which are used to define the offset between the target and a sky image, which is subsequently subtracted from all images.

This template records between 2 and 5 images to disk. On some occasions the operator will record two images of the AO reference, which are used to classify the OB. If this is the case, the image of the slit will be the third frame recorded to disk otherwise it will be first. The next image (either the 2nd or the 4th image recorded to disk) is an image of the acquisition target after it has been centred. If reference offsets are used, an additional image (either the 3rd or the 5th image recorded to disk) is taken after the reference offset.

Table 7-5: parameters of NACO_img_acq_MoveToSlit

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	F	Always set to F. PT not supported
Alpha offset from Ref star	0	Offset from reference star [arcsec]
Delta offset from Ref star	0	Offset from reference star [arcsec]
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec)	5	DEC offset for sky image
Position angle on sky	0	Position angle
Filter	NODEFAULT	Filter name (e.g. Ks)
Neutral Density Filter	ND_Short	Neutral density Filter (Full=none)
Camera	NODEFAULT	Camera Name (e.g. S27)
Slit	NODEFAULT	Slit name
NAOS parameter file	NODEFAULT	NAOS aocfg file from JNPS

7.3.5 NACO_img_acq_MoveToMask

This template does a telescope preset and is followed by interactive centring of the object behind the coronagraphic mask. It is very similar to the NACO_img_acq_MoveToPixel template; however, it must be followed by a coronagraphic template.

A drawing of the selected mask is displayed on the RTD and is superimposed on the image of the field. The centring of the target is then done interactively.

Acquisition must be done with the L27 objective for LW filters and can be done with either the S13 or S27 objectives for SW filters. For precise centring with the 4QPM mask, we recommend that users use the S13 objective. Note that when 4QPM masks are used, the mask itself is not taken out of the optical path (as was the case in the past) to avoid repositioning problems.

Table 7-6 describes the parameters of this template.

This template records either two or four images. If two images are recorded, then the first image is an image of the approximately centred target without the mask and the second image is an image of the target accurately centred behind the mask. If four images are recorded, then these images become, respectively, the 3rd and 4th images, and the first two are images of the reference and they are used by the operator to classify the OB.

In the case of the 4QPM masks and the semi-transparent mask (C_0.7_sep_10), the recorded images are:

- One flat on (halogen lamp is on) and one flat off image: these images can be used for flat fielding the subsequent science frames)
- An image of the star off the mask (~2" off, with the ND filter inserted if specified in the initial setup) and an image of the sky: these images can be used as PSF calibrator.

Then the following steps are performed:

- Rough offset to position the star behind the mask
- Removal of the ND_Short filter, if used. For 4QPM the Full_Uszd mask is used. All other masks use Full.
- Adjustment of DIT if needed
- Fine centring behind the mask
- Record the final acquisition image of the star finely centred behind the mask (without the ND filter).

Table 7-6: Parameters of NACO_img_acq_MoveToMask

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	F	Set to T for Pupil tracking observations.
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec)	5	DEC offset for sky image
Position angle on sky	0	Position angle or pupil angle in degrees.
Filter	NODEFAULT	Filter name (e.g. Ks)
Mask	NODEFAULT	Coronagraphic mask
Neutral Density Filter	Full	Neutral density Filter (Full=none)
Camera	NODEFAULT	Camera Name (e.g. S27)
NAOS Parameter file	NODEFAULT	NAOS aocfg file from JNPS

7.3.6 NACO_img_acq_SDIMoveToMask

This template does a telescope preset, which is followed by interactive acquisition of the object behind the 4QPM_H in combination with the SDI+ camera. It must be followed by the dedicated SDI+4 template, which uses the same instrument setup, with the possible exception for the use of the neutral density filter (ND_Short) for the acquisition of very bright targets. The use of the H band filter is recommended. The template records the following frames:

- One flat on (halogen lamp is on) and one flat off image: these images can be used for flat fielding the subsequent science frames)
- An image of the star off the mask (~2" off, with the ND filter inserted if specified in the initial setup) and an image of the sky: these images can be used as PSF calibrator.

Then the following steps are performed

- Rough offset to position the star behind the mask
- Removal of the ND_Short filter, if used. The Full_Uszd mask is inserted instead.
- Adjustment of DIT if needed
- Fine centring behind the mask
- Record the final acquisition image of the star finely centred behind the mask.

Table 7-7 describes the parameters of this template.

Table 7-7: Parameters of NACO_img_acq_SDIMoveToMask

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	F	Set to T for Pupil tracking observations.
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec)	5	DEC offset for sky image
Position angle on sky	0	Position angle or pupil angle in degrees.
Neutral Density Filter	Full_Uszd	Neutral density Filter (Full_Uszd=none)
BB filter wheel	H	Filter name (H or empty)
NAOS Parameter file	NODEFAULT	NAOS aocfg file from the JNPS

7.3.7 NACO_img_acq_Polarimetry

This template does a telescope preset and is followed by interactive centring of the object. It is very similar to the NACO_img _acq_MoveToPixel template; however, it must be followed by a polarimetric template that uses the Wollaston prism.

A drawing of the polarimetric mask is displayed on the RTD and is superimposed on the image of the field. The centring of the target is then done interactively.

Acquisition must be done with the L27 objective for LW filters or the S27 objective for SW filters. The subsequent polarimetric science templates allow one to set the angle before each template starts.

This template records an image of the field after the acquisition has been completed. If three images are recorded, then the first two are images of the reference and they are used by the operator to classify the OB.

Table 7-8 describes the parameters of this template.

Table 7-8: Parameters of NACO_img_acq_Polarimetry

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	F	Always set to F. PT not supported.
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec)	5	DEC offset for sky image
Position angle on sky	0	Position angle
Filter	NODEFAULT	Filter name
Neutral Density Filter	Full	Neutral density Filter (Full=none)
Camera	S27	Camera name
NAOS parameter file	NODEFAULT	NAOS aocfg file from the JNPS

7.3.8 NACO_img_acq_SAMMoveToPixel

This template does a telescope preset and then sets the pupil tracking mode sending the spiders to a pre-defined angle, which depends on the mask being used. This angle was chosen to prevent the telescope spiders from intersecting any holes. The rest of the acquisition is identical to that of NACO_img_acq_MoveToPixel. The template always saves the final acquisition image.

Table 7-9 describes the parameters of this template.

Table 7-9: Parameters of NACO_img_acq_SAMMoveToPixel

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
PSF Reference? (T/F)	F	Set to T if it is a PSF reference star
Pupil Tracking Mode? (T/F)	T	Always set to T. PT is compulsory.
RA offset (arcsec)	5	RA offset for sky image
DEC offset (arcsec	5	DEC offset for sky image
Position angle on sky	0	Position angle
Filter	NODEFAULT	Filter name
Sparse Aperture Mask	NODEFAULT	SAM mask
Camera	NODEFAULT	Camera name
NAOS Parameter file	NODEFAULT	NAOS aocfg file from JNPS

7.4 NaCo imaging science templates

For observations with the SW filters, the readout mode of the detector should be set to either Double_RdRstRd or FowlerNsamp. For observations with LW filters the readout mode should be set to Uncorr.

All imaging templates make use of the NEXPO per offset position parameter. It is the number of exposures (one exposure = DIT × NDIT) per offset position.

For very bright targets (see Sec. 5.15), a neutral density filter can be inserted into the light path. The choices are Full for no neutral density filter, ND_Long for a LW neutral density filter and ND_Short for a SW neutral density filter.

For LW observations without chopping, only the NACO_img_obs_AutoJitter template should be used. The sky subtraction with the other templates is generally unsatisfactory.

7.4.1 NACO_img_obs_AutoJitter

This template offsets the telescope between exposures according to a random pattern of offsets automatically determined by the template. It is ideal for long integrations on sparse fields, and does not require a long list of offsets to be defined.

The offsets are distributed randomly within a box whose size is defined by the parameter "Jitter Box Width" (in arc seconds), with the condition that the distance between any two points in a series of ten values is greater than a system-determined minimum. This is intentionally done to ensure that the 5 frames before and after any frame are spatially not too close and can be safely used for creating skies without residual objects for sky subtraction.

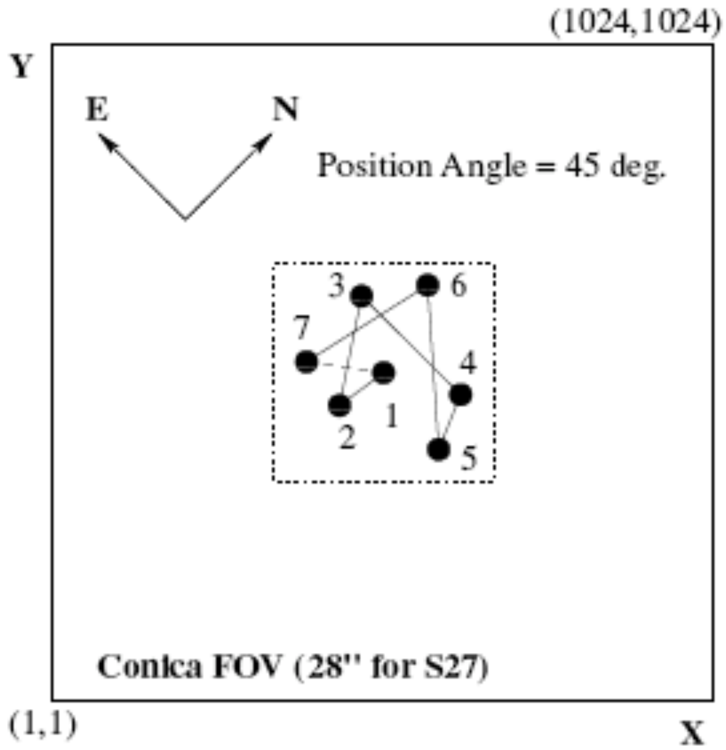


Figure 7-3: An illustration of the NACO_img_obs_AutoJitter. In this example the jitter box width is set to 10″, NEXPO is 1, number of offset position is 7, Return to Origin? is T and the camera is S27. The dotted line defines the jitter box width.

The value of the "Jitter Box Width" parameter corresponds to the full width of the box in which the offsets are generated. Defining too wide a box may lead to poor image overlap. Conversely, too small a value may lead to poor sky subtraction near extended objects.

By construction, there is no telescope offset before the first exposure. If the parameter "Return to Origin? (T/F)" is set to true (T) the telescope moves back to its original position at the end of the template. If not the telescope is not moved.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × NDIT × NEXPO per offset position × Number of offset positions

Table 7-10 describes the parameters of this template.

Table 7-10: Parameters of NACO_img_obs_AutoJitter

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Observation Category	SCIENCE	Observation Category
Store Data Cube? (T/F)	F	Data cube flag
Jitter Box width	NODEFAULT	Jitter box width
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Return to Origin? (T/F)	T	Return to origin at the end of the template
Filter	NODEFAULT	Filter name
Neutral Density Filter	Full	Neutral density filter (Full=none)
Camera	NODEFAULT	Camera Name

7.4.2 NACO_img_obs_GenericOffset

This template is used for imaging and has the flexibility to do any sequence of telescope offsets, either in detector or sky coordinates.

Table 7-11 describes the parameters of this template.

Telescope offsets are defined as lists with the parameters List of offsets in RA or X and List of offsets in DEC or Y. The offsets are relative to the previous position, are in RA and DEC or in X and Y depending on the Offset Coordinates parameter, and are defined in arcsec.

Additionally, the observation type can be defined for each image, and is entered as a list in the parameter "Observation Type (O or S)." O stands for Object and assigns the DPR.TYPE header keyword to OBJECT. S stands for Sky and assigns the DPR.TYPE header keyword to SKY. The AO loop is closed for the former and open for the latter.

The total number of offset positions is defined in the parameter "Number of offset positions." This number can be different from the number of elements in the aforementioned lists. Lists do not need to have the same length. If the number of exposures is larger than the number of elements in a list, the list is restarted from the beginning as many times as needed until the correct number of frames have been acquired.

The lists can have any length; however, having lists of different lengths can become extremely confusing. It is good practice to use lists of equal length or lists with only one value if one parameter is not changed.

At the end of the template, the telescope is returned to the original position. Figs. 20 and 21 illustrate how this template can be used.

The total integration time is defined, in seconds, by:

$$\mathrm{DIT} \times \sum^{\text{number of offset positions}} \mathrm{NDIT(i)} \times \text{NEXPO per offset position}$$

Table 7-11: Parameters of NACO_img_obs_GenericOffset

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Observation Category	SCIENCE	Observation Category
Store Data Cube? (T/F)	F	Data cube flag
List of NDITs	NODEFAULT	List of NDITs
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Observation type (O or S)	NODEFAULT	O is in closed loop, S in open loop
Offset coordinates	NODEFAULT	SKY or DETECTOR
List of offsets in RA or X	NODEFAULT	Offsets in arcsec
List of offsets in DEC or Y	NODEFAULT	Offsets in arcsec
Filter	NODEFAULT	Filter name
Neutral Density Filter	Full	Neutral density filter (Full=none)
Camera	NODEFAULT	Camera Name

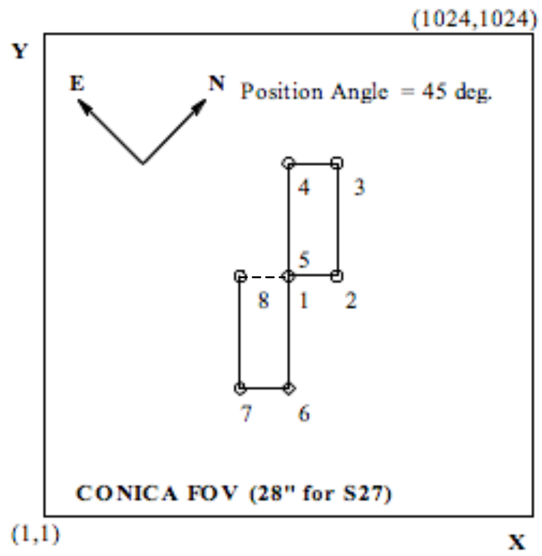


Figure 7-4: An illustration of how the NACO_img_obs_GenericOffset template works. In this example the offsets are in DETECTOR co-ordinates. Exposures 1 and 5 occur at the same place. The telescope will return to the origin after the eighth exposure, as indicated by the dashed line connecting point 8 to 1. The parameter settings for this example were:

Table 7-12: parameters for the example shown in Figure 7-4

NEXPO per offset position = 1	Observation Type (O or S)= O
Number of offset positions = 8	Offset Coordinates = DETECTOR
Camera = S27	List of offsets in RA or X = 0 3 0 -3 0 0 -3 0
	List of offsets in DEC or Y = 0 0 7 0 -7 -7 0 7

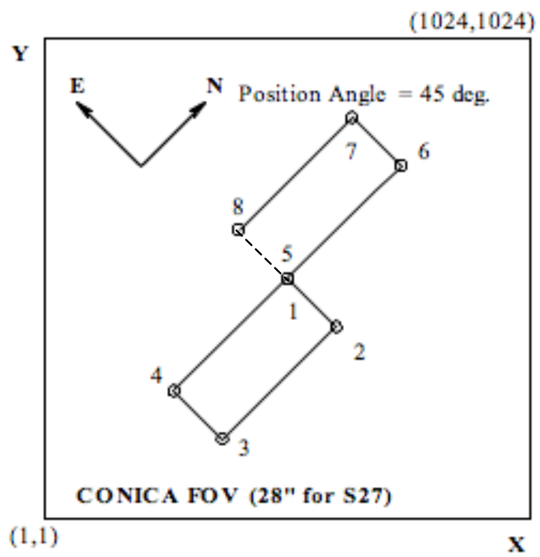


Figure 7-5: A second illustration of how the NACO_img_obs_GenericOffset template works. As with the previous example, exposures 1 and 5 occur at the same place, and the telescope returns to the origin after the eighth exposure (indicated by the dashed line connecting point 8 with 1/5). The parameter settings for this example were:

Table 7-13: : parameters for the example shown in Figure 7-5

NEXPO per offset position = 1	Observation Type (O or S)= O
Number of offset positions = 8	Offset Coordinates = SKY
Camera = S27	List of offsets in RA or X = 0 4 0 -4 0 0 -4 0
	List of offsets in DEC or Y = 0 0 8 0 -8 -8 0 8

7.4.3 NACO_img_obs_AutoChopNod

This template combines imaging with M2 chopping and telescope nodding. It can only be used with the LW filters. The number of nodding cycles is referred to as Number of AB or BA cycles and one cycle, commonly called an AB cycle, consists of two exposures, one at each end of the nod. The orientation of the chopping is defined with the Chop Position Angle parameter. This parameter can be defined in terms of SKY or DETECTOR coordinates with the Chop/Nodding Coordinate parameter.

Additionally, it is possible to jitter between ABBA cycles, but not between AB or BA cycles. The amount of jitter between ABBA cycles is defined by the Jitter Box Width parameter (in arcsec). For the removal of hot pixels it is essential that Jitter Box Width be set to a non zero value.

If the parameter "Return to Origin? (T/F)" is set to true (T) the telescope moves back to its original position at the end of the template. If not the telescope is not moved.

The total integration time (excluding overheads) is defined in minutes. In general, the user will get slightly more or slightly less time than what was specified in the OB. This is because the DIT is set so that the detector does not saturate, the number of NDITs is set by the chopping frequency and the number of cycles is set so that approximately 30 to 60 seconds are spent at each end of the nod.

To compute the actual integration time from the information provided in the FITS header one needs to compute

DIT × NDIT × 2 × Number of cycles × Number of AB or BA cycles × 2.

Table 7-14: parameters of NACO_img_obs_AutoChopNod

P2PP Label	Default Values	Description
Chop/Nodding coordinate	NODEFAULT	SKY or DETECTOR coordinates
Chop Position Angle	NODEFAULT	Chop Position angle (deg)
Chop Throw	NODEFAULT	M2 Chop Throw (arcsec)
Integration time (minutes)	NODEFAULT	Total Integration Time
Jitter Box Width	NODEFAULT	Jitter box width
Return to Origin? (T/F)	T	Return to Origin at the end of the template
Filter	NODEFAULT	Filter name
Neutral Density Filter	Full	Neutral density filter (Full=none)
Camera	NODEFAULT	Camera Name

7.4.4 NACO_img_obs_FixedSkyOffset

This template moves the telescope alternatively between 'object' and 'sky' positions. The 'object' positions are randomly distributed around the initial telescope position and within a box whose dimensions are set by the parameter "Jitter Box Width" (in arcsec).

The 'sky' positions are randomly distributed around a position that is set at a constant distance (defined by the parameters "Sky offset in DEC" and "Sky offset in RA") from the original telescope position and within a box whose dimensions are set by the parameter "Jitter Box Width" (in arcsec).

The 'object' positions' will be observed with the AO loop closed. For the 'sky' positions, the AO loop will be open. Table 7-15 describes the parameters of this template.

By default, there is no telescope offset before the first exposure. The telescope moves back to its original position at the end of the template.

The Number of AB or BA cycles defines the number of OBJECT-SKY or SKY-OBJECT cycles to be executed. These cycles are executed in ABBA sequences. E.g. if Number of AB or BA cycles is set to 3, 6 exposures will be taken in an ABBAAB sequence.

In addition, the template provides the flexibility to adjust the number of NDIT sub-integrations for the OBJECT and SKY frames. NDIT for the OBJECT positions defines the number of sub-integrations on the object, and NDIT for the SKY positions defines the number of sub-integrations on the sky.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × (NDIT for the OBJECT positions + NDIT for the SKY positions) × NEXPO per offset position × Number of AB or BA cycles

Thus, the total integration time on the sky and on the object can be adjusted so that the S/N on the object is optimised. Remember that the "30 second per telescope position rule" means here that both (DIT x NDIT for the OBJECT positions × NEXPO per offset position plus overheads) and (DIT × NDIT for the SKY positions × NEXPO per offset position plus overheads) shall each exceed 30 seconds of time.

Table 7-15: Parameter of NACO_img_obs_FixedSkyOffset

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Data cube flag
Jitter box width	NODEFAULT	Jiter Box Width
Number of AB or BA cycles	NODEFAULT	One cycle is one object-sky pair
NDIT per object position	NODEFAULT	Number of DITs for the OBJECT
NDIT per sky position	NODEFAULT	Number of DITs for the SKY
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Sky offset in RA	NODEFAULT	RA offset in arcsec
Sky offset in DEC	NODEFAULT	Dec offset in arcsec
Filter	NODEFAULT	Filter name
Neutral Densty Filter	Full	Neutral density filter (Full=none)
Camera	NODEFAULT	Camera Name

Figure 7-6 illustrates how this template can be used.

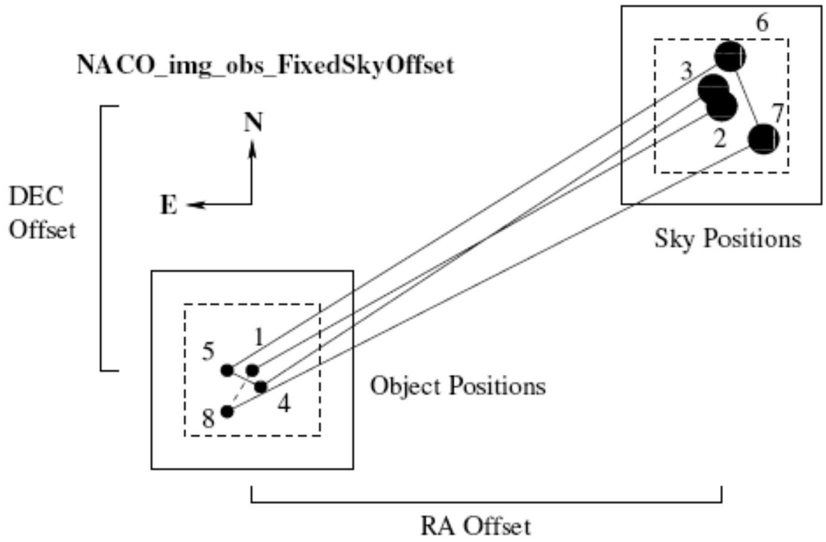


Figure 7-6: An illustration of how the NACO_img_obs_FixedSkyOffset template works with:

Jitter Box Width = 9
Number of AB or BA cycles = 4
Sky offset in Dec. = 15
Sky offset in RA. = -35
Camera = S13

The AO loop is off when the sky is observed (large filled in circles) and on when the object is observed (small filled in circles). The dashed line connecting 8 with 1 is the offset done at the end when the telescope returns to origin. The dashed box is defined by the Jitter Box Width.

7.4.5 NACO_img_cal_StandardStar

This template is used for imaging standards and is similar to the NACO_img_obs_GenericOffset template with the difference that some DPR keywords in the FITS headers of the images are set to different values allowing pipeline processing and archiving. Additionally, NDIT is single valued in this template and offsets are in detector coordinates only.

This template should be used by all users who wish to take calibrations (standard stars observation) beyond the ones provided by the Calibration Plan. Table 7-16 describes the parameters of this template

Table 7-16: Parameters of NACO_img_cal_StandardStar

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Data cube flag
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
List of offsets in X	NODEFAULT	Offsets in arcsec
List of offsets in Y	NODEFAULT	Offsets in arcsec
Filter	NODEFAULT	Filter name
Neutral Density Filter	Full	Neutral density filter (Full=none)
Camera	NODEFAULT	Camera Name

7.4.6 NACO_img_cal_ChopStandardStar

This template is used for standard star observations that require chopping. It is strictly equivalent to the NACO_img_obs_AutoChopNod template in the definition of the parameters. (7.4.3).

This template should be used by users who need calibrations (standard stars) beyond the ones provided by the Calibration Plan of this mode.

The only difference with NACO_img_obs_AutoChopNod is that some DPR keywords in the FITS headers of the images are set to values that allow pipeline processing and archiving.

7.5 Simultaneous Differential Imaging (SDI+) template

The simultaneous differential imager (SDI+) uses special templates to acquire and observe targets.

7.5.1 NACO_sdi_obs_GenericOffset

This template is used exclusively with the SDI+ mode. It is similar to the NACO_pol_obs_GenericOffset template in that it allows one to rotate the field of view as well as offset the telescope.

At each rotator angle, the telescope offsets according to a user-defined list. Offsets are defined with the parameters List of offsets in X and List of offsets in Y. They are relative to the previous position, are in detector co-ordinates and are defined in arcsec. Additionally, the observation type can be defined for each image, and is entered as a list in the parameter "Observation Type (O or S)." O stands for Object and assigns the DPR.TYPE header keyword to OBJECT. S stands for Sky and assigns the DPR.TYPE header keyword to SKY. The AO loop is closed for the former and open for the latter.

The total number of spatial offsets is defined by the parameter "Number of offset positions" This number can be different from the number of elements in the aforementioned lists. If the number of spatial offsets is larger than the number of elements in a list, the list is restarted from the beginning as many times as needed until the correct number of offsets has been done. These lists can have any length; however, having lists of different lengths can become extremely confusing. It is good practice to use lists of equal length or lists with only one value if one parameter is not changed.

Unlike other templates, this template does not have a "Return to Origin ? (T/F)" flag. This flag refers to the spatial offsets only and the template will do this automatically before rotating the rotator to the new position.

Table 7-17 describes the parameters of this template.

Rotator offset angles are entered as a list. The angles are relative, so a sequence with 0 33 0 -33 would result in images that are taken 0, 33, 33 and 0 degrees from the original rotator position. Due to difficulties in compensating for rotator offsets with the FS, we are presently requesting observers to keep the relative offset angle to 45 degrees or less.

Additionally, the user can choose to rotate the rotator to the original rotator position once the template has ended with the parameter Return to the Original Rotator Position?(T/F). For observations with NAOS-CONICA, the default value for this flag is False.

The total number of exposures is given by:

number of rotator positions × Number of offset positions × NEXPO per offset position

With this scheme, it is possible for the user to sample the object and the sky as desired at several rotator positions. It is also possible to code the template so that the object and sky are sampled as desired for one angle only. The template can be restarted with another orientation on the sky for another series of exposures.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × NDIT × NEXPO per offset position × Number of offset pos × number of rotator pos.

Table 7-17: Parameters of NACO_sdi_obs_GenericOffset

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Data cube flag
List of NDITs	NODEFAULT	List of NDITs
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Observation type (O or S)	NODEFAULT	O is in closed loop, S in open loop
List of offsets in X	NODEFAULT	Offsets in arcsec
List of offsets in Y	NODEFAULT	Offsets in arcsec
Return to the Original Rotator position? (T/F)	F	Rotator position at the end of the template.
List of position angle offsets	NODEFAULT	List of rotator offsets in degrees
Neutral Density Filter	Full	Neutral density filter (Full=none)

7.6 NaCo spectroscopic science templates

For SW observations, the readout mode of the detector can be set to either FowlerNsamp or Double_RdRstRd; for LW observations, the readout mode will be set to Double_RdRstRd.

The width of the slitless mask is 13 arc seconds, which is half the length of the regular slits. Users should keep this point in mind when programming the offsets. For the NACO_spec_obs_AutoNodOnSlit and NACO_spec_cal_StandardStar templates, this means that the nod throw should be less than 10″.

7.6.1 NACO_spec_obs_AutoNodOnSlit

This template nods the telescope between two positions (A and B) along the slit. A cycle is a pair of AB or BA observations. Cycles are repeated on ABBA sequences. E.g. 3 cycles correspond to an ABBAAB sequence, 4 cycles correspond to an ABBAABBA sequence, etc.

Table 7-18 describes the parameters of this template.

The mean size of the nod is defined by the Nod throw parameter. The first exposure (A) is taken after offsetting the object along the slit by +NodThrow/2 arcsec. The second exposure (B) is therefore (-NodThrow/2) from the initial position along the slit. In addition to nodding, random offsets can be added in the middle of a cycle. A sequence of 6 cycles with jittering will result in the following sequence:

$A(B+E_1)(B+E_1)(A+E_2)(A+E_2)(B+E_3)(B+E_3)(A+E_4)\ (A+E_4)(B+E_5)(B+E_5)(A+E_6)$

where E_n are random offsets. In order to avoid the possibility of overlapping spectra, E_n should be smaller than half of the nod throw.

The random offsets are generated inside an interval defined by the parameter "Jitter Box Width" (in arcseconds). Offsets are randomly distributed between (-JitterBoxWidth/2) and (+JitterBoxWidth/2). It is **strongly** recommended to define some non-zero value for the Jitter Box Width parameter, as this allows one to get several images with the spectra lying at different positions on the detector. However, it should be smaller than the Nod throw, otherwise spectra on either side of the throw could overlap.

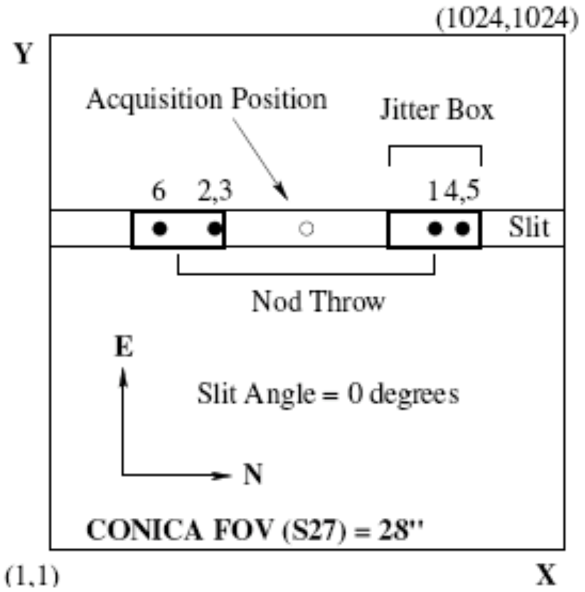


Figure 7-7: An illustration of how the NaCo spec obs AutoNodOnSlit template works with:
Jitter Box Width = 5, Return to Origin?= T, Number of AB or BA cycles = 3, NEXPO per offset position = 1, Nod throw = 15.

To better exploit the jittering facility offered by this template, it is also recommended to define the Number of AB or BA cycles to some value higher than 1, e.g. 4 or 5 so as to get several AB pairs of images with the spectra lying at different positions across the array.

If the parameter "Jitter Box Width" is set to zero, then the template will just nod between A and B. If the parameter "Return to Origin? (T/F)" is set to true (T) the telescope returns to the starting position. If not the telescope is not moved.

The NEXPO per offset position parameter defines the number of frames stored per A or B position. If, for example, DIT = 120s, NDIT = 1, NEXPO per offset position = 8, 8 images will be stored for each position. If, in addition, the Number of AB or BA cycles is set to 2, the template will deliver in total 32 images, 8 for the first A position, 16 for the B position, and 8 for the second A position. The total integration time (excluding overheads) is 64 minutes.

Note: in the case where there are several OBs using this template on the same target (for several hours of integration on the same target), it is recommended to modify the Nod throw parameter by a few arcsec between each OB. This is for the following reason: the acquisition is always done at the same position on the array (i.e. centre of the slit). Therefore, different executions of the same template will position the targets at the same positions along the slit, and the spectra will fall at the same positions on the detector. Therefore, even if you define some non-zero value for the Jitter Box Width parameter, it is recommended to give the Nod throw parameter different values between OBs so as to get the spectra at different positions across the array.

When defining the nod throw, users are requested to ensure that other objects in the slit do not cause the spectra to overlap when the throw is executed.

The total number of frames is:

Number of AB or BA cycles × NEXPO per offset position × 2.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × NDIT × NEXPO per offset position × 2 × Number of AB or BA cycles

Table 7-18: Parameters of NACO_spec_obs_AutoNodOnSlit

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	FowlerNsamp	Readout mode
Jitter Box Width	NODEFAULT	Jitter Box Width
Number of AB or BA cycles	NODEFAULT	One cycle is one object-sky pair
NEXPO per offset position	1	Number of exposures per offset position
Nod Throw	NODEFAULT	Nod Throw in arcsec
Return to Origin? (T/F)	T	Return to Origin
Slit	NODEFAULT	Name of slit
Spectroscopic Mode	NODEFAULT	Spectroscopic Mode

7.6.2 NACO_spec_obs_GenericOffset

This template is used for spectroscopy and has the flexibility of programming any sequence of telescope offsets. It is essentially intended for programs requiring large offsets (off the slit), or slit scanning across one object.

Table 7-19 describes the parameters of this template

Telescope offsets are defined as lists with the "List of offsets in RA or X" and "List of offsets in DEC or Y" parameters. Telescope offsets are relative, defined either along detector lines (X) and columns (Y) or RA and DEC, and are in arcsec. Offsets in X are along the slit, offsets in Y are perpendicular to the slit.

Additionally, the observation type can be defined for each image, and is entered as a list in the parameter "Observation Type (O or S)." O stands for Object and assigns the DPR TYPE header keyword to OBJECT. S stands for Sky and assigns the DPR TYPE header keyword to SKY. The loop is closed for the former and open for the latter.

With large combined offsets, the guide probe may not be able to follow the same guide star. In such a case, the guiding system will automatically find another star, but not resume guiding. A pop up window will instruct the operator to resume guiding. If the guide star has changed during an offset, the accuracy of the offset will be poorer than it would have been if the same guide star had been used. This will only occur when offsetting from object to sky. On the return offset, the loop will close and the field selector in NAOS will make sure that the object remains centred in the slit even though the guide star has changed.

The total number of offset positions is defined in the parameter "Number of offset positions" This number can be different from the number of elements in the aforementioned lists. Lists do not need to have the same length. If the number of exposures is larger than the number of elements in a list, the list is restarted from the beginning as many times as needed until the correct number of frames have been acquired.

The lists can have any length; however, having lists of different lengths can become extremely confusing. It is good practice to use lists of equal length or lists with only one value when one parameter remains constant.

This template allows slit scanning across an object by defining a list of offsets in the Y direction.

If the parameter "Return to Origin? (T/F)" is set to true (T) the telescope returns to the starting position. If not the telescope is not moved.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × NDIT × Number of offset positions × NEXPO per offset position

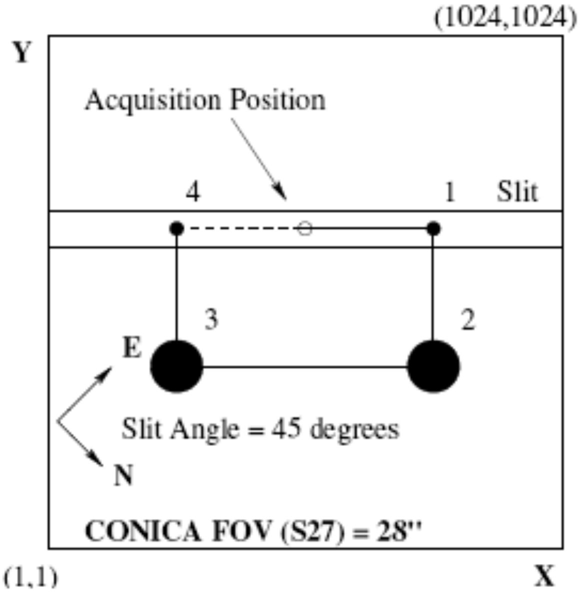


Figure 7-8: An illustration of how the NACO_spec_obs_GenericOffset template works. The AO loop is off when the sky (S) is observed (large filled in circles) and on when the object (O) is observed (small filled in circles). The dashed line connecting 4 with the acquisition position is the offset done at the end of the telescope since the Return to Origin ? (T/F) was set to T. In this example the parameter settings were:

Number of offset positions = 4
NEXPO per offset position = 1
Observation Type (O or S) = O S S O
Offset Coordinates = DETECTOR
List of offsets in RA or X = 7 0 -14 0
List of offsets in DEC or Y = 0 -7 0 7
Return to Origin ? (T/F) = T

Table 7-19: Parameters of NACO_spec_obs_GenericOffset

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	FowlerNsamp	Readout mode
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Observation type (O or S)	NODEFAULT	O is in closed loop, S in open loop
Offset coordinates	NODEFAULT	SKY or DETECTOR
List of offset in RA or X	NODEFAULT	Offsets in arcsec
List of offset in DEC or Y	NODEFAULT	Offsets in arcsec
Return to Origin ?(T/F)	T	Return to Origin
Slit	NODEFAULT	Name of slit
Spectroscopic Mode	NODEFAULT	Spectroscopic Mode

7.6.3 NACO_spec_cal_StandardStar

This template is used for spectroscopic standard star observations. It is strictly equivalent to the NACO_spec_obs_AutoNodOnSlit template in the definition of the parameters. The user is referred to 7.6.1 for the description of the parameters.

This template should be used by users who need calibrations beyond the ones provided by the Calibration Plan of this mode.

The differences with NACO_spec_obs_AutoNodOnSlit are that some DPR keywords in the FTTS headers of the images are set to different values allowing pipeline processing and archiving.

7.6.4 NACO_spec_cal NightCalib

This template is used for taking nighttime arcs and flat fields and it should be placed immediately after the spectroscopic templates.

If Night Arc? (T/F) is set to T, a pair of exposures, one with the arc lamp on and another with the arc lamp off will be taken. If set to F, no arcs are taken

If Number of Night Flats is set n, where n can be from 0 to 3, n pairs of exposures are taken. Each pair consists of one exposure with the flat field lamp on and one exposure with the flat field lamp off. If n is set to zero, the default, no lamp flats are taken.

Table 7-20 describes the parameters of this template

Table 7-20: Parameters of NACO_spec_cal_NightCalib

P2PP Label	Default Values	Description
Night arc? (T/F)	F	Night time arc
Number of night flats	0	Number of flat field on/off pairs.

7.7 NaCo polarimetry science templates

These templates are for polarimetric observations with the Wollaston prism.

For SW observations, the readout mode of the detector should be set to either Double_RdRstRd or FowlerNsamp. For LW observations, the readout mode should be set to Uncorr. All other combinations will be rejected at the time the OBs are checked.

For very bright target, a neutral density filter can be inserted into the light path. The choices are Full for no neutral density filter, ND_Long for a LW neutral density filter and ND_Short for a SW neutral density filter.

Since the J-band filter is in the same wheel as the Wollaston, J-band polarimetric observations are not feasible.

7.7.1 NACO_pol_obs_GenericOffset

This template is used for imaging polarimetry. It can be used with all filters with the exception of J and Mp. Rotator offset angles can now be entered as a list. The angles are relative, so a sequence with 0 45 45 45 would rotate the field by 0, 45, 90 and 135 degrees from the original rotator position. Due to difficulties in compensating for rotator offsets with the FS, we are presently requesting observers to keep the relative offset angle to 45 degrees or less.

Additionally, the user can choose to rotate the rotator to the original rotator position once the template has ended with the parameter Return to the Original Rotator Position? (T/F). For observations with NAOS-CONICA the default value for this flag is False.

After each rotator offset, the telescope can offset according to a user defined list. Spatial offsets are defined with the parameters List of offsets in X and List of offsets in Y. The offsets are relative to the previous position, are in X and Y and are defined in arcsec. Additionally, the observation type can be defined for each image, and is entered as a list in the parameter "Observation Type (O or S)." O stands for Object and assigns the DPR TYPE header keyword to OBJECT. S stands for Sky and assigns the DPR TYPE header keyword to SKY. The AO loop is closed for the former and open for the latter.

The total number of spatial offsets is defined by the parameter "Number of offset positions" This number can be different from the number of elements in the aforementioned lists. If the number of spatial offsets is larger than the number of elements in a list, the list is restarted from the beginning as many times as needed until the correct number of offsets has been done. These lists can have any length; however, having lists of different lengths can become extremely confusing. It is good practice to use lists of equal length or lists with only one value if one parameter is not changed.

The total number of exposures is given by:

$$\text{number of rotator positions} \times \text{Number of offset pos} \times \text{NEXPO per offset pos}$$

Unlike other templates, this template does not have a "Return to Origin ? (T/F)" flag. This flag refers to the spatial offsets only and the template will do this automatically before rotating the rotator to the new position. Table 7-21 describes the parameters of this template.

With this scheme, it is possible for the user to sample the object and the sky as desired at several rotator positions. It is also possible to code the template so that the object and sky are sampled as desired for one angle only. The template can be restarted with another orientation on the sky for another series of exposures.

At least two different orientations, separated by 45 degrees, are required for computing the Stokes parameters.

To image the entire field of view at one position angle, one must take great care with the offsets. The opaque and transmitting parts of the mask have slightly different widths. The opaque strips have a width of 3.9″ and the transmitting strips have a width of 3.1″. An example of how one may choose to image the entire field of view is given in Figure 7-9.

The total integration time (excluding overheads) is defined, in seconds, by:

$$\text{DIT} \times \text{NDIT} \times \text{NEXPO per offset pos} \times \text{Number of offset pos} \times \text{number of rotator pos}$$

Table 7-21: Parameters of NACO_pol_obs_GenericOffset

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	Double_RdRstRd	Readout mode
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Observation type (O or S)	NODEFAULT	O is in closed loop, S in open loop
Offset coordinates	NODEFAULT	SKY or DETECTOR
List of offset in X	NODEFAULT	Offsets in arcsec
List of offset in Y	NODEFAULT	Offsets in arcsec
Return to the original rotator position ?(T/F)	F	Return to original rotator position at the end of the template
List of position angle Offsets	NODEFAULT	List of rotator offsets in degrees
Filter	NODEFAULT	Filter Name
Neutral density filter	Full	Neutral Density filter
Camera	NODEFAULT	Camera Name

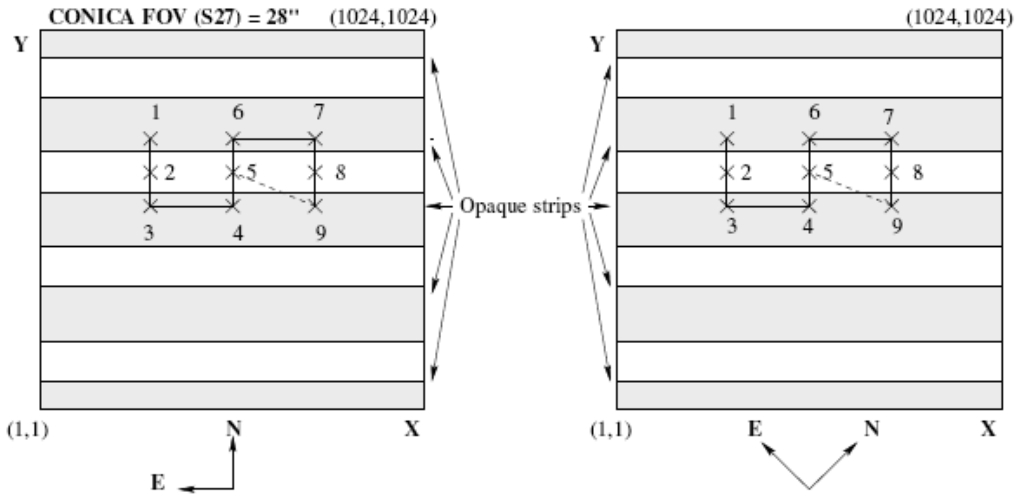


Figure 7-9: An illustration of how the NACO_pol_obs_GenericOffset template works with:
Number of offset positions = 9
NEXPO per offset position = 1
Observation Type (O or S) = O
List of offsets in X = -4 0 0 4 0 0 4 0 0
List of offsets in Y = 2.3 -2.3 -2.3 0 2.3 2.3 0 -2.3 -2.3
List of Position Angle Offsets = 0 45

The dashed line connecting position 9 with 5 is the offset done after the 9th and 18th exposures. Position 5 corresponds to the position the target was acquired. This sequence has been designed so that the entire field of view is covered.

7.7.2 NACO_pol_obs_Retarder

This template is used for imaging polarimetry (without chopping) exclusively with the half-wave plate. It can be used with all filters with the exception of J and Mp and with the Wollaston prism.

This templates works with defined (generic) offsets. It must follow the acquisition template NACO_img_acq_Polarimetry.

For each given offset position, the template runs over the list of half-wave plate angles before moving to the next offset position. Only at the end of the OB does the telescope move back to the original position and the half-wave plate to its default position (i.e. 0). The angles in the list of half-wave plate angle are relative one from the other, e.g. (0, 22.5, 22.5, 22.5) would correspond to an absolute rotation of (0, 22.5, 45, 67.5). Note that the first angle provided is absolute, since the HWP is always set to its zero position at the beginning of the template.

Once the template has run over the list of half-wave plate angles, the telescope can offset according to a user-defined list. Spatial offsets are defined with the parameters List of offsets in X and list of offsets in Y. The offsets are relative to the previous position, are in X and Y and are defined in arcsec. Additionally, the observation type can be defined for each image, and is entered as a list in the parameter "Observation Type (O or S)." O stands for Object and assigns the DPR TYPE header keyword to OBJECT. S stands for Sky and assigns the DPR TYPE header keyword to SKY. The AO loop is closed for the former and open for the latter.

The total number of spatial offsets is defined by the parameter "Number of offset positions" This number can be different from the number of elements in the aforementioned lists. If the number of spatial offsets is larger than the number of elements in a list, the list is restarted from the beginning as many times as needed until the correct number of offsets has been done. These lists can have any length; however, having lists of different lengths can become extremely confusing. It is good practice to use lists of equal length or lists with only one value if one parameter is not changed.

The total number of exposures is given by:

NEXPO per offset pos × number of half-wave plate angle × Number of offset pos

Unlike other templates, this template does not have a "Return to Origin? (T/F)" flag. By default at the end of the template the telescope returns at the original position. It is important to remember that for technical reasons the HWP is moved into the beam, and set to its zero position at the beginning of the template and then it is moved out of the beam at the end of the template. This introduces an extra 1-minute overhead per template.

Table 7-22 describes the parameters of this template.

The template can be restarted with another orientation on the sky for another series of exposures.

At least two different half-wave plate orientations, separated by 22.5 degrees, are required for computing the Stokes parameters. By definition a rotation of the polarisation plane by 45 degrees does correspond to a rotation of the half-wave plate by 22.5 degrees.

To image the entire field of view, while observing with the Wollaston prism the same care must be taken as for observation with the NACO_pol_obs_GenericOffset template (see 6.8.2). The total integration time (excluding overheads) is defined, in seconds, by:

DIT × NDIT × NEXPO per offset pos × number of half-wave plate angle × Number of offset pos

The angle of the HWP used is reported in the FITS header under INS.RETA2.NAME. Previously this keyword did not exist. The angle of the HWP can be retrieved from INS.ADC1.ENC (HWP encoder) via the following formula:

HWP angle = (HWP encoder + 205) / (4096/360) – modulo 4096

Example: angles of 0 & 22.5 correspond to INS.ADC1.ENC = 3891 & 51 respectively. This information remains available from the FITS header.

Table 7-22: Parameters of NACO_pol_obs_Retarder

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	Double_RdRstRd	Readout mode
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Observation type (O or S)	NODEFAULT	O is in closed loop, S in open loop
List of offset in X	NODEFAULT	Offsets in arcsec
List of offset in Y	NODEFAULT	Offsets in arcsec
List of position angle offsets	NODEFAULT	List of HWP angles
Filter	NODEFAULT	Filter Name
Mask	NODEFAULT	Set to Wollaston_00
Neutral density filter	Full	Neutral Density filter
Camera	NODEFAULT	Camera Name

Note that Mask should always be set to Wollaston_00.

7.7.3 NACO_pol_cal_StandardStar

This template should be used to observe polarimetric standards that do not require chopping. It is strictly equivalent to the NACO_pol_obs_GenericOffset (see 7.7.1) template with the difference that some DPR keywords in the FITS headers of the images are set to different values allowing pipeline processing and archiving

7.8 NaCo coronagraphic science templates

For SW observations, the readout mode of the detector should be set to either Double_RdRstRd or to FowlerNsamp.

7.8.1 NACO_coro_obs_Stare

This template is used for coronagraphic observations and it moves the telescope alternatively between a fixed object position and a sky position. The parameter Number of AB or BA cycles defines the number of times this is done, but, unlike the NACO_spec_obs_AutoNodOnSlit, and NACO_img_obs_FixedSkyOffset templates, the sequence is ABABAB and not ABBAAB for the example in which the Number of AB or BA cycles is set to 3.

The number of exposures at the object position is defined by the Number of Exposures (Object Only) parameter. The telescope does not offset between these exposures.

The number of exposures at the sky position is defined by the Number of offset positions (Sky only) and the telescope can offset between these exposures. The 'sky' positions are randomly distributed around a position that is set at a constant distance (defined by the parameters "Sky offset in DEC" and "Sky offset in RA") from the original telescope position and within a box whose dimensions are set by the parameter "Jitter Box Width" (in arcsec). It is strongly recommended, especially for very bright sources to select an area so that the main target is out of the field of view for sky measurements (to avoid saturation effects). The coronagraphic mask is left in the beam for the sky exposures.

The 'object' positions will be observed with the AO loop closed. The 'sky' positions will be observed with the AO loop open.

Table 7-23 describes the parameters of this template.

The template provides the flexibility to adjust the number of NDIT sub-integrations for the OBJECT and SKY frames. NDIT for the OBJECT positions defines the number of sub-integrations on the object, and NDIT for the SKY positions defines the number of sub-integrations on the sky.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × (NDIT for the OBJECT pos × Number of Exposures (Object Only) + NDIT for SKY positions × Number of offset positions (Sky only)) × Number of AB cycles

If Number of offset positions (Sky only) is set to zero, the sky is not observed. In this case the total integration time is

DIT × NDIT for the OBJECT positions × Number of Exposures (Object Only)

and all other parameters are ignored. In this way the template takes a series of exposures of the target without offsets. However, sky subtraction is almost always required, so this option will probably only be used in very special circumstances.

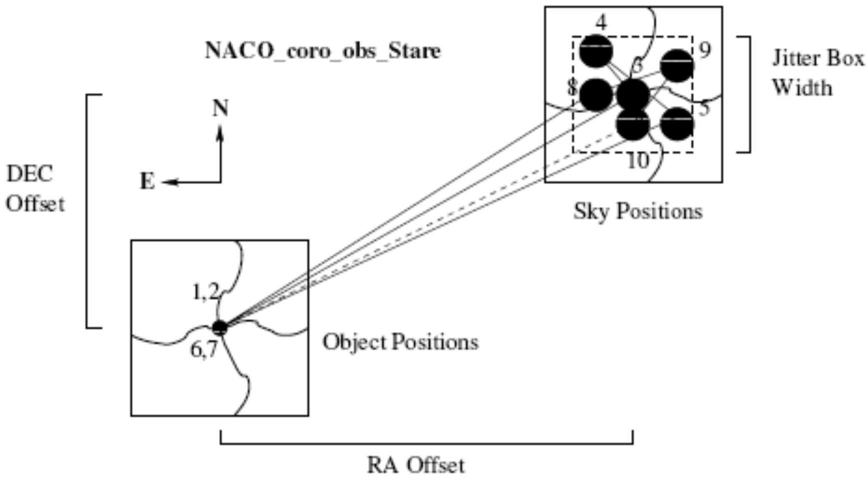


Figure 7-10: An illustration of how the NACO_coro_obs_Stare template works. The dashed line connecting position 10 with 1 is the offset done at the end of the template, when the telescope returns to origin. The rather erratic bold lines are wires, which hold the coronagraphic mask in place. The AO loop is off when the sky is observed (large filled in circles) and on when the object is observed (small filled in circles). In this example, the parameter settings were:

Number of AB cycles = 2
Number of Exposures (Object Only) = 2
Number of offset positions (Sky only) = 3
Jitter Box Width = 9
Sky offset in Dec. = 15
Sky offset in RA. = -35
Camera = S13

Table 7-23:Parameters of NACO_coro_obs_Stare

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Store in data cube flag
Jitter Box Width	NODEFAULT	Jitter box width (SKY only)
Number of AB cycles	NODEFAULT	Number of AB cycles (e.g. 2 for ABAB)
NDIT for OBJECT positions	NODEFAULT	Number of DITs for OBJECT
NDIT for SKY positions	NODEFAULT	Number of DITs for SKY
Number of exposures (Object only)	NODEFAULT	Number of exposures on target
Number of offset positions (Sky only)	NODEFAULT	Number of exposures on sky
Sky offset in RA	NODEFAULT	RA offset for sky in arcsec
Sky offset in DEC	NODEFAULT	DEC offsets for sky in arcsec
Filter	NODEFAULT	Filter Name
Mask Position	NODEFAULT	Coronagraphic mask
Camera	NODEFAULT	Camera Name

7.8.2 NACO_coro_obs_Astro

This template is used for coronagraphic observations.

It runs after a normal coronagraphic acquisition. It takes "NEXPO Obj only" images of a target behind the coronagraphic mask without moving the telescope. Then the coronagraphic mask is removed and (NOFF (img) - 1) are taken.

The last offset provided in the NOFF IMG list moves the telescope onto the sky position (Generic offset principle). There the mask is inserted again and on an "auto-jitter" manner, NOFF SKY images are taken on sky. The idea is to get images of the target with and without the coronagraphic mask. Since most sources are too bright for simple imaging, there exists the possibility to define a different filter set-up for the 'imaging' part of the template.

The number of coronagraphic images to be taken on the source is defined by NEXPO CORO. NOFF CORO defines the number of sky images to be taken with the coronagraphic mask. The integration time (DIT CORO) is forced to be identical for all data taken with the coronagraphic mask, but NDIT can be different for images with the target (NDIT Obj) and on sky (NDIT Sky). The Readout mode can be selected but remains the same throughout all the template. For the imaging part of the template (= where no coronagraphic mask is used), DIT IMG & NDIT IMG can be defined independently of the rest of the template. Similarly the number of exposures per position (NEXPO IMG) and the number of offsets (NOFF IMG) are free parameters.

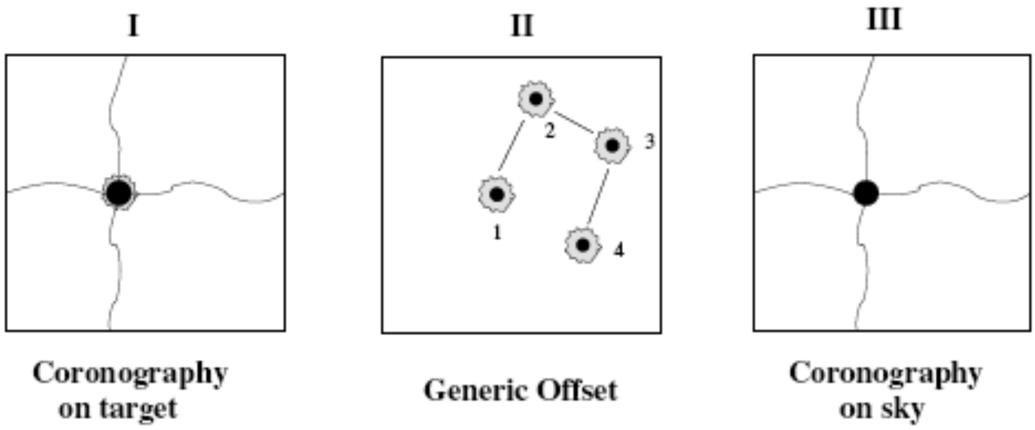


Figure 7-11: Illustration of how the NACO_coro_obs_Astro template works. The 3 phases of the template are presented. Part I (left): coronagraphy without moving the telescope. Part II (middle): simple imaging (the coronagraphic mask is removed). Normally the first offset is zero, to measure the exact position of the target out of the mask. The last offset of the list (NOFF SKY) brings you onto the sky position, where the original coronagraphic mask is inserted again and on sky coronagraphic images are taken in open loop (Part III - right diagram). In this example, NOFF SKY = 5.

Table 7-24 describes the parameters of this template.

The total integration time (excluding overheads) is defined, in seconds, by the sum of the "CORO" time and "IMAGING" time (= time spent on each mode respectively).

CORO exposure = DIT CORO × NDIT OBJ × NEXPO OBJ + DIT CORO × NDIT SKY × NOFF SKY IMG exposure = DIT IMG × NDIT IMG * NEXPO IMG * NOFF IMG.

When using the 4QPM masks, if no neutral density filter is needed, it is recommended to use the Full_Uszd mask.

Table 7-24: Parameters of NACO_coro_obs_Astro

P2PP Label	Default Values	Description
NDIT (img)	NODEFAULT	Number of DITs for the imaging
DIT (coro)	NODEFAULT	DIT (sec) for coronagraphy
DIT (img)	NODEFAULT	DIT (sec) for imaging
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Store in data cube flag
Jitter Box Width	NODEFAULT	Jiter box width (sky only)
NDIT for object position	NODEFAULT	Number of DITs at the object pos. under the mask
NDIT for sky position	NODEFAULT	Number of DITs at the sky pos. with the mask
NEXPO Obj only (coro)	NODEFAULT	Number of exp. with target under the mask
NEXPO per offset pos (img)	NODEFAULT	Number of exp. per imaging position
NOFF sky only (coro)	NODEFAULT	Num. of offset pos on sky (with the mask)
NOFF (img)	NODEFAULT	Number of offset positions for imaging
Offset coordinates	NODEFAULT	SKY or DETECTOR
List of offset in X	NODEFAULT	Offsets in arcsec
List of offset in Y	NODEFAULT	Offsets in arcsec
Filter (coro)	NODEFAULT	Filter Name (for coronagraphy)
Filter (img)	NODEFAULT	Filter Name (for imaging)
Mask Position	NODEFAULT	Coronagraphic mask
Neutral Density Filter	Full	Neutral Density filter
Camera	NODEFAULT	Camera Name

7.8.3 NACO_coro_cal_NightCalib

This template is used for taking nighttime flat fields and it should be placed immediately after the coronagraphic or the SDI+4 templates.

If Number of Night Flats is set to n, where n can be from 0 to 3, n pairs of exposures are taken. Each pair consists of one exposure with the flat field lamp on and one exposure with the flat field lamp off. If n is set to zero, no lamp flats are taken. The default is one.

This template should be used to take flats with the 4QPM, the semi-transparent coronagraphic mask and SDI+4. Only the SW filters are supported. LW lamp flats are not possible. For the LW filters, the only alternative is to use a sky frame to flat field the data.

Table 7-25 describes the parameters of this template.

Table 7-25: Parameters of NACO_coro_cal_NightCalib

P2PP Label	Default Values	Description
Number of night flats	1	Night time flat field

7.8.4 NACO_coro_cal_StandardStar

This template is used to observe standards with the semi-transparent coronagraphic mask. It is similar to the NACO_img_obs_GenericOffset template (see section 6.5.3), with the difference that some DPR keywords in the FITS headers of the images are set to values that allow pipeline processing and archiving. Additionally, NDIT is single valued in this template and offsets are in detector coordinates only.

Users should specify the offsets with some care, as the purpose of this template is to allow photometry with the glass plate that holds the coronagraphic mask. Images of the coronagraphic masks are available from the NaCo web pages.

This template can also be used to observe photometric standards with the masks that are held by the wires (C_0.7 and C_1.4). In this case, the masks will not be inserted in the focal plane, but the correct pupil mask will.

Table 7-26 describes the parameters of this template.

Table 7-26: Parameters of NACO_coro_cal_StandardStar

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
NDIT	NODEFAULT	Number of DITs
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Data cube flag
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
List of offsets in X	NODEFAULT	Offsets in arcsec
List of offsets in Y	NODEFAULT	Offsets in arcsec
Filter	NODEFAULT	Filter name
Mask psition	C_0.7_sep_10	Coronagraphic mask
Camera	NODEFAULT	Camera Name

7.9 NaCo SDI+4 scientific templates

For SDI+4 observations, the readout mode of the detector should be set to either Double_RdRstRd or to FowlerNsamp.

7.9.1 NACO_sdi4_obs_Stare

This template is used for SDI+4 observations and it moves the telescope alternatively between a fixed object position and a sky position. The parameter Number of AB or BA cycles defines the number of times this is done, but, unlike the NACO_spec_obs_AutoNodOnSlit and NACO_img_obs_FixedSkyOffset templates, the sequence is ABABAB and not ABBAAB for the example in which the Number of AB or BA cycles is set to 3.

This part of the template works identically to NACO_coro_obs_Stare.

The number of exposures at the object position is defined by the Number of Exposures (Object Only) parameter. The telescope does not offset between these exposures.

The number of exposures at the sky position is defined by the Number of offset positions (Sky only) and the telescope can offset between these exposures. The 'sky' positions are randomly distributed around a position that is set at a constant distance (defined by the parameters "Sky offset in DEC" and "Sky offset in RA") from the original telescope position and within a box whose dimensions are set by the parameter "Jitter Box Width" (in arcsec). It is strongly recommended, especially for very bright sources to select an area so that the main target is out of the field of view for sky measurements (to avoid saturation effects). The coronagraphic mask is left in the beam for the sky exposures.

The 'object' positions will be observed with the AO loop closed. The 'sky' positions will be observed with the AO loop open. Table 7-27 describes the parameters of this template.

The template provides the flexibility to adjust the number of NDIT sub-integrations for the OBJECT and SKY frames. NDIT for the OBJECT positions defines the number of sub-integrations on the object, and NDIT for the SKY positions defines the number of sub-integrations on the sky.

The total integration time (excluding overheads) is defined, in seconds, by:

DIT × (NDIT for the OBJECT positions × Number of Exposures (Object Only) + NDIT for the SKY positions × Number of offset positions (Sky only)) × Number of AB cycles

If Number of offset positions (Sky only) is set to zero, the sky is not observed. In this case the total integration time is

DIT x NDIT for the OBJECT positions × Number of Exposures (Object Only)

and all other parameters are ignored. In this way the template takes a series of exposures of the target without offsets. However, sky subtraction is almost always required, so this option will probably only be used in very special circumstances.

Note that an additional overhead of 2 minutes for target re-centring has to be considered every time that Number of Exposures (Object Only) is greater than 1

Table 7-27: Parameters of NACO_sdi4_obs_Stare

P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	F	Data cube flag
Jitter Box Width	NODEFAULT	Jitter box width (sky only)
Number of AB cycles	NODEFAULT	Number of AB cycles, e.g. 2 for ABAB
NDIT for OBJECT positions	NODEFAULT	Num of DITs per object position
NDIT for SKY positions	NODEFAULT	Num of DITs per sky position
Number of exposures (object only)	NODEFAULT	Number of exposures on target
Number of offset positions (sky only)	NODEFAULT	Number of exposures on sky
Sky offsets in RA	NODEFAULT	RA offset in arcsec
Sky offsets in DEC	NODEFAULT	DEC offset in arcsec

7.10 NaCo SAM science templates

There is only one SAM template for p82. With the possible commissioning of SAMPol (SAM+Polarimetry) at the end of p82, another template supporting this mode will be added.

7.10.1 NACO_sam_obs_GenericOffset

The science template is similar to NACO_img_obs_GenericOffset.

Note that, however not compulsory, SAM will use cube mode for data storage as a default. This, and the handling of the offsets in pupil tracking mode, account for most of the differences with the NACO_img_obs_GenericOffset. Cube mode is highly recommended with the Double_RdRstRd setup. FowlerNSampling has very large overheads and users should weight the loss of time carefully against the advantage of lower noise.

In the most basic mode (i.e. recommended setup), SAM will typically require a 512x514 sub frame, and observations will occur in pairs that are dithered between two separate quadrants (e.g. bottom left, top right). Offsets must be given in DETECTOR cordinates, to avoid that the changing position angle on sky, introduced by the pupil-tracking mode in use with SAM, puts the objects in ever different locations on the detector, or worse, outside of the available field. The operator always centers accurately the object on pixel (512,512) and the subsequent offset sequence can be of the type: offsets in X (1 -2), offsets in Y (1 -2), with the result that the stars goes from upper right to lower left. Another possible sequence, uses all four quadrants alternatively: offsets in X (1 -2 0 2) and offsets in Y (1 -2 2 -2) will move the object from the center to upper right to lower left, to upper left and finally to the lower right quadrant.

Sky observations will be dealt with as usual (open loop, offset set by the user in the offset sequence, always in DETECTOR coordinates). Table 7-28 describes the parameters of this template.

As always in cube mode, DIT=0 will set the minimum integration time allowed for the specific readout mode and window size. The NDIT for each frame is limited by the final cube file size, set to a maximum of 512 MB. For each exposure it can be set to a different number (i.e. list of NDIT can be 2000, 50 100 100). Since most SAM objects are bright, it is always convenient using cube mode and perform shift and add techniques during post-processing of the data.

Please refer to section 5.8 for information on the available setups.

Table 7-28: Parameters of NACO_sam_obs_GenericOffset

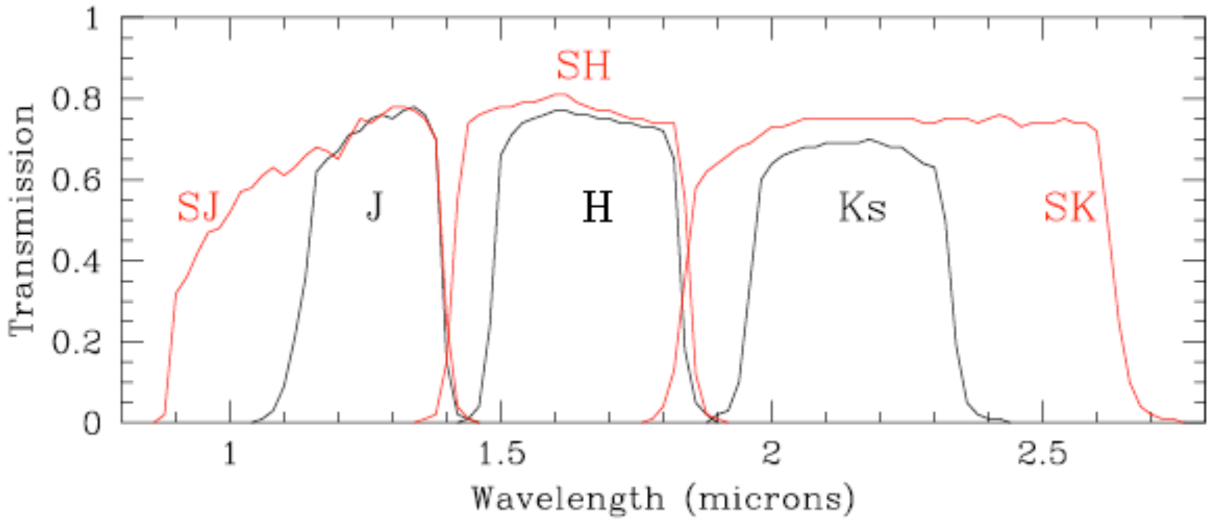
P2PP Label	Default Values	Description
DIT	NODEFAULT	Detector Integration Time (sec)
Readout mode	Double_RdRstRd	Readout mode
Window Size	1024	Size of the window
Store Data Cube? (T/F)	T	Data cube flag
List of NDITs	NODEFAULT	List of NDITs
NEXPO per offset position	1	Number of exposures per offset position
Number of offset positions	NODEFAULT	Number of offset positions
Observation type (O or S)	NODEFAULT	O is in closed loop, S in open loop
Offset coordinates	NODEFAULT	Choose DETECTOR
List of offsets in RA or X	NODEFAULT	Offsets in arcsec
List of offsets in DEC or Y	NODEFAULT	Offsets in arcsec
Filter	NODEFAULT	Filter name
SAM Mask	Full	Name of SAM mask
Camera	NODEFAULT	Camera Name

8 FILTER TRANSMISSION CURVES

8.1 CONICA Broad Band Imaging and order sorting filters

The transmission curves at the J, H, Ks, Lp, Mp, and spectroscopic order-sorting filters are displayed in Figure 8-1. Electronic versions of the transmission curves of all filters, including the NB and IB filters, are available from the NaCo web pages:

http://www.eso.org/sci/facilities/paranal/instruments/naco/inst/filters.html



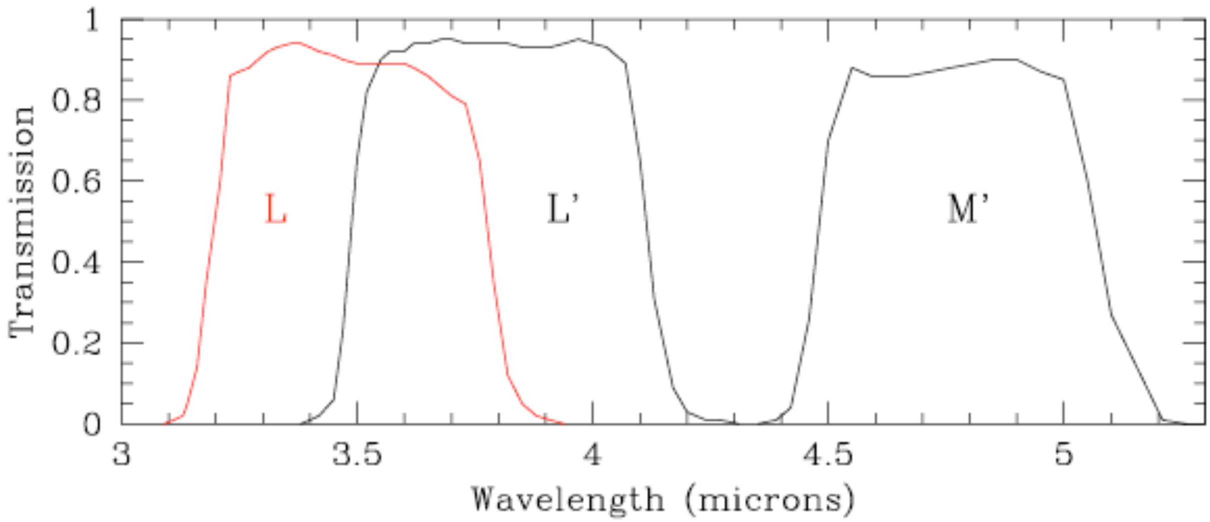


Figure 8-1: Filter curves for J, H, Ks, Lp and Mp and the order-sorting spectroscopic filters SJ, SK, L. The SH and L band filters are also used as order-sorting filters in spectroscopy

8.2 CONICA Neutral Density Filters

CONICA is equipped with a short wavelength (1 to 2.5 μm) and a long-wavelength (>2.5 μm) neutral density filter. The wavelength dependence of the attenuation is shown in Figure 8-2

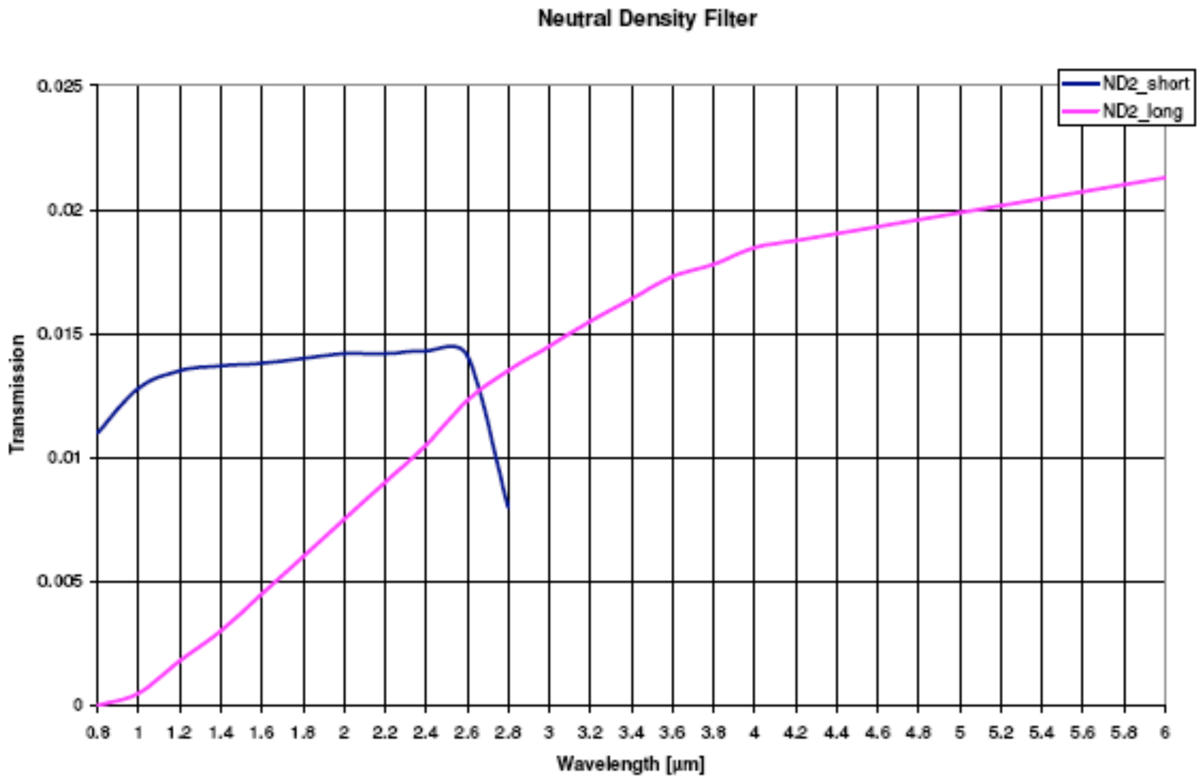


Figure 8-2: Transmission curves of the CONICA neutral density filters.

9 PREPARATION SOFTWARE

This section describes the Preparation Software (PS), which is a key tool in the preparation of OBs in both Visitor and Service Mode.

The purpose of the PS is to find the optimal NAOS configuration for a given set of conditions, to compute the associated performance and to provide input to P2PP and the ETC.

Input to the PS is done through a Graphical User Interface (GUI) and includes atmospheric conditions, such as seeing and airmass, target parameters, such as the observing wavelength and the dichroic, and reference source parameters, such as brightness, morphology and the distance between reference and target.

Output consists of a configuration file for P2PP (Sec. B.8), an estimate of the performance in terms of Strehl, a 2-dimensional PSF, and an HTML formatted file (Sec. B.7) for the ETC.

The ETC can be accessed via the web based interface at http://www.eso.org/observing/etc/ or via the HTML file produced by PS.

Finally, in the course of the execution of the observations at the telescope, the PS is able to take into account the current external conditions and actual reference (instead of expected) source characteristics to optimize the observations, still respecting the astronomer's requirements for observing wavelength, transmission, and so on. The FITS headers of NaCo data contain all the necessary information on the setup used.

Users can select the WFS directly. This will allow users to use the N90C10 dichroic as neutral density filter for CONICA when using the visual WFS. Additionally, we have updated some parameters to better reflect the average conditions of the atmosphere above Paranal.

9.1 Starting the PS

The NAOS Preparation Software can be downloaded for a number of computer platforms at the following URL: http://www.eso.org/observing/etc/naosps/doc/. After installation, a link to the general server situated at ESO will be required (i.e. the local computer has to have access to the Internet).

In principle, JNPS will work within any Java Virtual Machine which supports Java Development Kit (JDK) 1.5.0 or later. It has been reported to work using a variety of Unix and Linux flavors, as well as MacOs X. Until further notice, ESO will only officially support JNPS under Scientific Linux 4.3.

The PS client is started by typing the command: jnps

After initialization, the main GUI will appear. The start-up procedure partly depends on the contents of your preferences file, which is created in your home directory when you start the PS for the first time. This file, called .jnpscf, contains the user's choices for several items, some of which can be accessed via the Preferences menu of the main GUI.

9.2 Graphical User Interface Overview

The GUI that appears after the initialization phase is depicted in Figure 9-1. The panel is divided into three areas, which are, from top to bottom:

- The menu bar, giving access to file-related operations and other miscellaneous functionalities (see following sections).

- The main panel, divided in four sub-areas which respectively deal with the science target, the reference object, the sky conditions, and resulting performance (image quality).
- The action area, gathering general actions such as requests for optimization, or creation of the P2PP parameter file and the HTML file for the ETC.

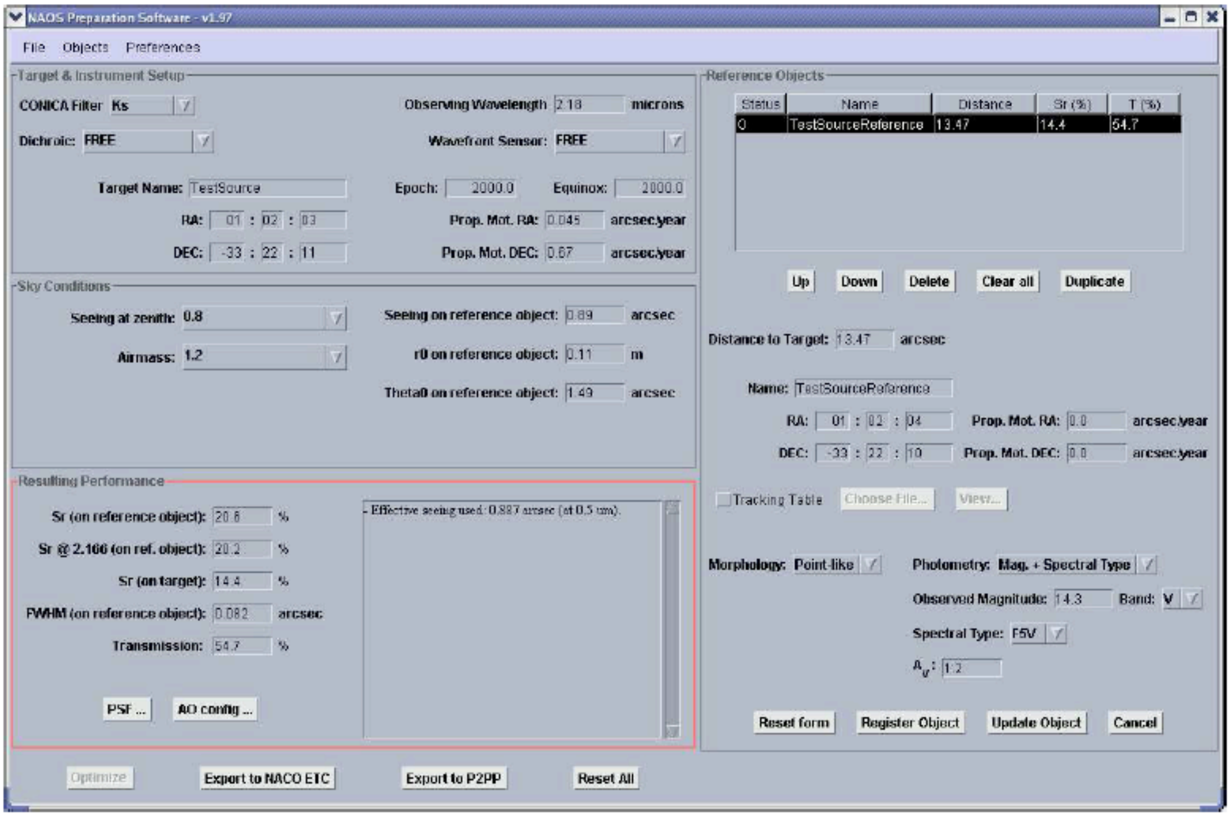


Figure 9-1:PS GUI

9.3 Target and Instrument Setup

The observing wavelength (in µm) can be entered as a filter, in which case the wavelength automatically appears, or it can be entered directly by selecting free from the list of CONICA filters and then typing the value directly into the space provided.

The dichroic name can be selected or left free. If left free the PS will select the dichroic, which maximizes the Strehl, which usually means that most of the light will be sent to NAOS. If another dichroic is preferable, then the dichroic can be selected here. Table 4-1 gives the conditions under which the various dichroics should be used. Users should familiarize themselves with the contents of this table.

In particular, the most critical choice will be between the N90C10 and N20C80 dichroics. The former will result in higher Strehl ratios but much lower sensitivity, particularly in the K band. The N90C10 dichroic can also be selected with the visible WFS in order to reduce the flux transmitted to CONICA (for instance with a very bright source).

In a similar way, the wavefront sensor can be selected. This is where one can indicate the wish to use the laser guide star (LGS). Only if the WFS has been selected as LGS will an LGS mode be proposed to the user.

There are borderline cases when one has to decide whether to select LGS or NGS mode. The limiting magnitude is currently m_V=13.5-14, i.e. with AO reference stars which are fainter than this limit one should select LGS mode and keep the star as a tip tilt reference. Brighter stars offer better performance in NGS mode. When using the PS, a good rule of thumb is the following: if the expected Strehl ratio calculated for the NGS mode is 10% or higher, stay with NGS. Otherwise move to LGS.

Until further notice, no mixed configurations (or dual OBs) are allowed: if the first choice is LGS, the second cannot be NGS with VIS-WFS.

Moreover only PIs that explicitly requested LGS in Phase I will be granted its use.

Target information consists of a name, coordinates and proper motion. For the proper motion to be taken into account, it is compulsory to provide both epoch and equinox for which the coordinates are provided. The corresponding coordinates at the time of observation does correspond to the precessed coordinates at the mean epoch for a given period, i.e. 2007.0 for P78, 2007.5 for P79 and so on; this is the hard coded epoch of the reference target. The epoch of the science target is a free parameter to set (between 1850. & 2100.). The target and AO reference star can have different proper motion. It is however assumed that the coordinates are given for the same equinox.

9.4 Sky Conditions

The user characterizes the observing conditions via two parameters, the seeing (at Zenith and measured at 0.5µm) and the airmass.

The "on axis" quantities, such as the seeing on the reference, are automatically computed from these two parameters and some assumptions about the average wind speed and isoplanatic angle on Paranal. The Fried parameter (r_0) and the isoplanatic angle θ_0 are also displayed. All on-axis quantities are computed at 0.5 µm.

9.5 Reference Objects

The information about reference objects is gathered on the right hand part of the main GUI.

For LGS-operations, the natural guide star for tip-tilt correction (TTS) has to be specified. Ease of operations requires that only one TTS can be specified per LGS OB.

9.5.1 Handling several reference objects

It is possible to keep a list of several possible reference objects for observations (in NGS) and work alternatively with each of them. The list of reference objects is shown as a table at the top of the form containing all the data pertaining to the reference object. Each row corresponds to a reference object, showing its name – if it has been provided - and its angular distance to the science target (mandatory parameter). The other columns are filled when requesting an optimization by the PS server (section B.6). If several reference objects are available in the table, you can select the one you want to work with by simply clicking on the corresponding row. This will update the contents of the form below the table, as well as the Resulting Performance sub-panel shown on the bottom left of the GUI. Indeed, each reference object is attached to its own configuration of the AO system, and to the performance estimated when considering this configuration.

The order is important: if the first reference object is acquired successfully, then the other reference objects will not even be considered. Reference objects should be sorted in decreasing order of expected performance. Use the list manipulation buttons (Up/Down) to modify this order as needed.

Every time you want to add an object to the list, you must first fill in the mandatory fields, and then click the button labelled Register Object, at the bottom of the reference object form. The mandatory fields are:

- the coordinates of the reference, which sets the distance to target,
- the reference brightness and
- the reference morphology

If the reference object is the target, one can use the Target → Reference Object option from the Objects menu at the top of the panel as a shortcut.

For test purposes, the interface can be run without knowing the precise coordinates of the target nor the reference object. In this case, one need only enter the separation between the two. But names and coordinates must be supplied if the interface is being used for OB preparation.

The default morphology of the reference object is point-like, which does not need any additional input. Other morphologies can be specified.

Other buttons that can be seen next to Register Object are:

- **Reset Form:** this simply erases the form without confirmation.
- **Update Object**: if you are modifying the characteristics of a reference object which is already recorded in the table, this button will automatically turn red, reminding you to click this button to record your changes.
- **Cancel:** cancel any changes to the selected reference

Underneath the table is another set of buttons, which allows one to manipulate the list of reference objects:

- **Up/Down**: moves the selected object in the list, by swapping it with its neighbor. The order in which the reference objects are shown will be the one exported to P2PP (Sec. B.8) and hence the one tried at the telescope.
- **Delete:** this discards all data pertaining to the selected reference object. A confirmation dialog is shown to prevent mistakes.
- **Clear all**: same as above, except that all reference objects of the table will be erased.
- **Duplicate:** makes a copy of all the characteristics of the currently selected reference object, and adds it at the bottom of the list. This may prove useful if you want to experiment with a reference object and you want to be able to compare different results of optimization while keeping all of them in the GUI, instead of simply overwriting the results.

9.5.2 Morphology

The Preparation Software - and the NAOS instrument - can also handle moderately extended objects (up to 3 arcsec in diameter) to analyze the incoming wavefront. Several models are available to define the morphology of the reference object.

Objects with one of three different morphologies can be used as NAOS reference objects:

- Point-like object
- Binary object, which requires:
  - an angular separation between the two components, given in the range (0,2.5] in arcsec, and

- the flux ratio of the two components ([{flux of fainter companion} / {flux of brighter component}]; dimensionless).

- o Disc-like object. When using a resolved object in the solar system, you are asked to enter its diameter, in arcsec. This morphology is modeled by a limb-darkened disk.

9.5.3 Photometry

The PS also has to compute the flux coming from the reference object. Since the WFS spectral bandwidths are very large, a single magnitude is not sufficient to compute the detected number of photons. The photometric information may be provided in different ways:

- o Magnitude + Spectral Type. Well suited to main sequence stellar objects. If you choose this option, you will need to enter the apparent magnitude, the filter in which the magnitude is measured (either V, J, H, K, Lp or Mp), and a spectral type. The spectral type is chosen in an option button. The list of available values is the same as that available in the interface of the CONICA ETC. This ensures the compatibility between the two tools, especially in the case when the target is also used as the reference object (see also section B.7).
- o Magnitude + Temperature. The magnitude is given in the same way as above (value + filter), but, in this case, the spectral energy distribution is modeled as a black body, which requires a temperature.

Moreover the users now have the possibility to provide a visible extinction, A_V value; by default and if not specified this value is 0 and the PS behaves exactly as before. When A_V is defined it governs by how much the brightness of the AO reference target changes as function of the wavelength; which is especially important due to the broad bandwidth of the wavefront sensor detectors. We adopted a standard extinction law, represented in Figure 9-2, as defined by Cardelli, Clayton & Mathis (AJ 345, 245 (1989) - section IIIb), and expressed as:

$$< A(\lambda)/A_V >= a(x) + b(x)/R_V \quad \text{with} \quad R_V = A_V / E(B-V) \qquad (1)$$

We set $<R_V>$ to 3.1, which is an average value for the interstellar medium and is essentially independent of A_V for wavelength longer than 0.7μm.

9.5.4 Tracking table

For objects with high proper motions, and this usually means solar system objects, the usual set of coordinates is not sufficient. The user has to provide a separate tracking table, giving the relative offsets between the AO reference object and the target in arcsec ([AO reference - science target] coordinates), as a function of universal time (UTC). An example of the format of this tracking table is given in Figure 9-3. The file containing the tracking data must be edited by hand and be available on the user's local disk. Checking the Tracking Table check-button (below the coordinates entries) enables the Choose File button next to it. You can then attach your file to the selected reference object, and the tracking table can also be seen via the View button, which is enabled as soon as the file is attached. Please note that the data of the tracking table are then copied into the interface, which means that you do not need to keep the original file on your disk, except of course if you want to edit your data. You would then have to re-attach the table to the reference object. If you changed your mind and do not want the tracking table anymore, just deselect the Tracking Table check-button.

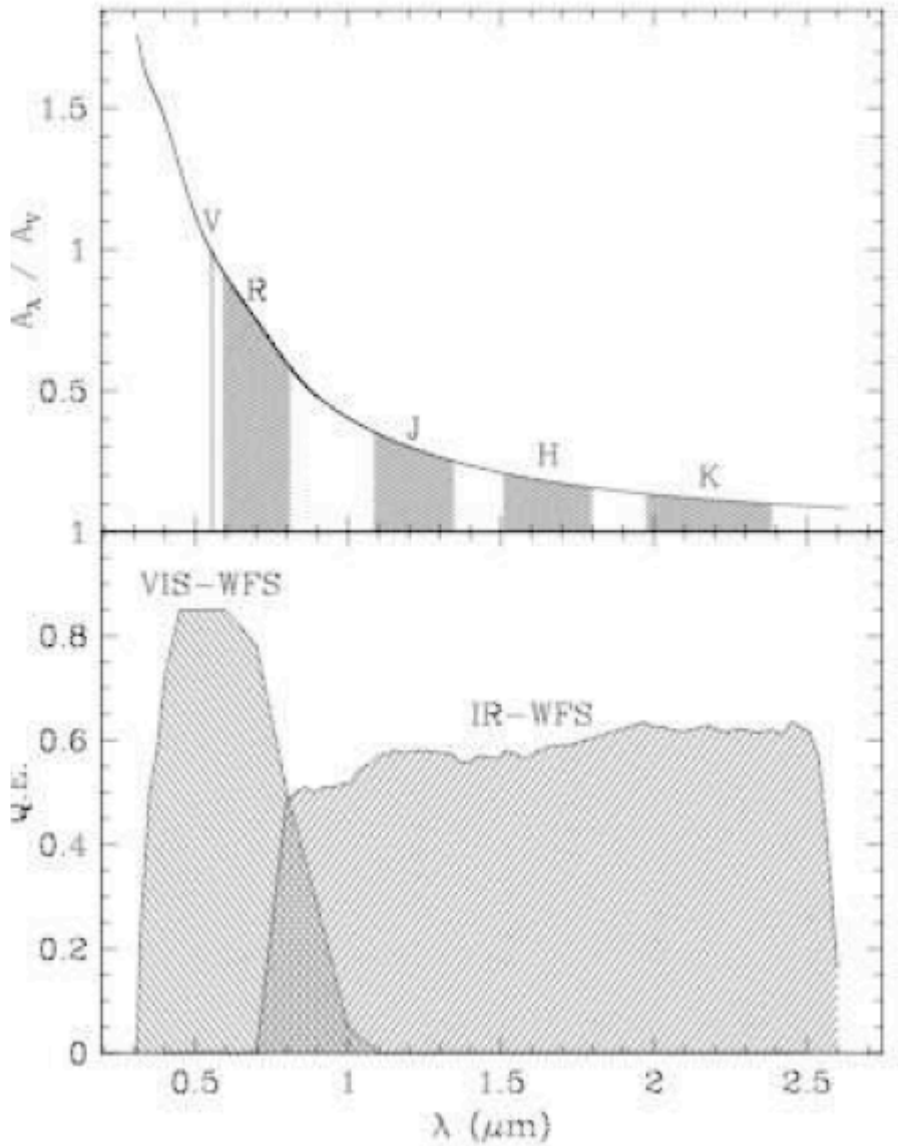


Figure 9-2: Illustration of the extinction curve used when giving a non zero value to the extinction A_V . The J, H, K and R bands are shown for reference along with the monochromatic wavelength for V. The bottom graph represents the quantum efficiency for the WFS detectors as a function of wavelength.

9.5.5 Optimizing NAOS and Getting a Performance Estimation

The optimal configuration (i.e. the one giving the highest Strehl) and the resulting PSF are determined when the Optimize button, located in the bottom left corner of the graphical user interface, is selected. The typical response time from the server is 10 seconds, and should not exceed 60 seconds. When more than one reference object has been defined, the optimization is done for the selected (highlighted) one. For complete preparation, the Optimize command should be repeated for each (potentially) viable reference object.

Once you have made a request for optimization, and if it has been successfully processed, the GUI will be updated with the optimal AO configuration (Figure 9-4) and an estimation of the resulting PSF. The Strehl ratio is always computed for the reference object (on-axis) at the observing wavelength and at 2.166 μm. For the science target (off-axis) the Strehl ratio is given at the observing wavelength only.

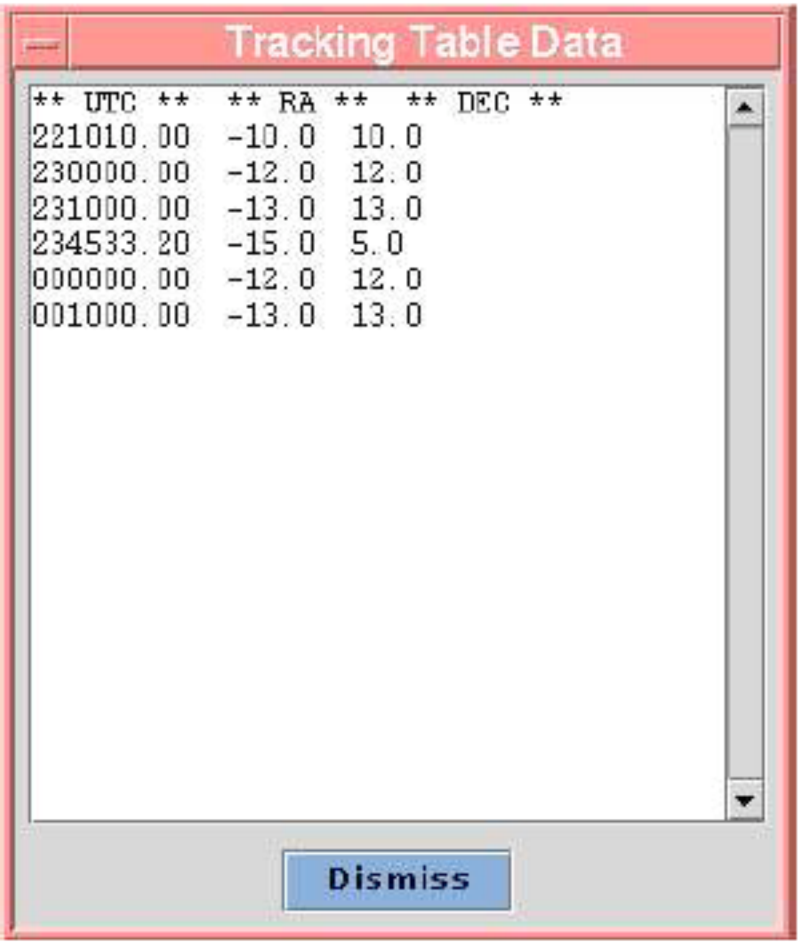


Figure 9-3: An example of tracking table window (acquisition and observation of moving objects). Offsets in RA and DEC are given in arcsec.

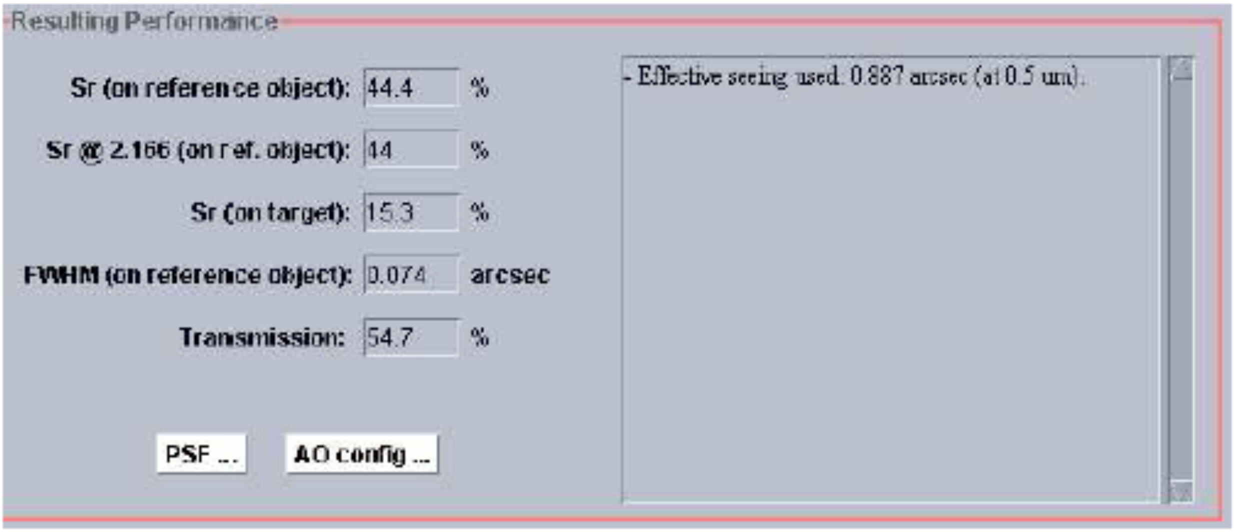


Figure 9-4: Performance subpanel: the AO optimal configuration and the PSF is available from buttons in this panel.

The optimal Adaptive Optics configuration can be displayed by clicking on the AO Config button in the subpanel depicted in Figure 33. An example is shown in Figure 9-5.

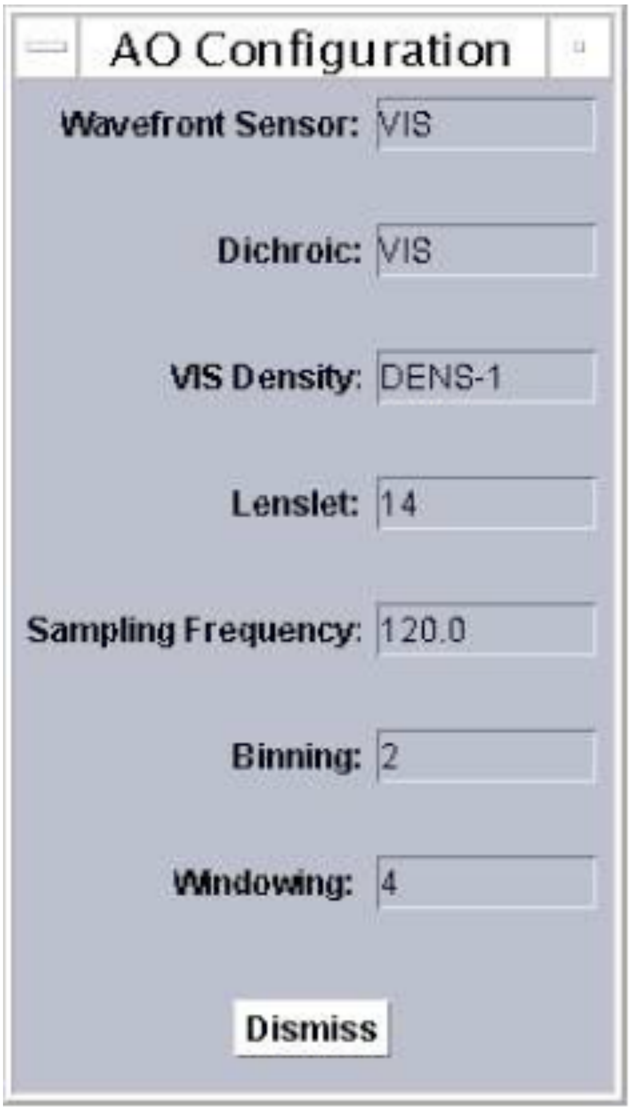


Figure 9-5: Pop-up window showing an optimal configuration of the AO system.

You do not have to worry about these parameters, but they may give you some insight into the way NAOS works.

From the perspective of the astronomer, the most significant result of the optimization is the corresponding estimated performance in terms of image quality. It is expressed quantitatively by the computed point-spread function (PSF) and its derived quantities.

The PSF is returned to the user interface in FITS format. It characterizes the quality of the optical beam, which is provided by NAOS to CONICA, and is thus logically computed at the observing wavelength, and is available from the Resulting Performance area of the GUI. The provided PSF is computed off-axis, i.e., in the direction of the target seen by CONICA. The PS computes these data on 128x128 pixels. One pixel corresponds to an angle of $\lambda/2D$ and the extracted PSF is assumed to be monochromatic. To access the PSF data once the optimization has been performed, click on the PSF button. This pops up a window that shows the profile of the PSF along the x- and y-axes (Figure 9-6). The FITS file itself can also be saved to the user's local disk for later use. If you want to save the file, the Save PSF button brings a file browser and allows you to choose the name of the file on your local disk. This operation is performed by sending the appropriate request to the central server, where your PSF file has been stored under a unique name. Depending on your local installation, the file retrieval may take a few seconds.

The other quantities which are outputs of the optimization are:

- The Strehl ratio is expressed as a percentage. It is derived from the PSF, and as such it is linked to the observing wavelength. The on-axis Strehl ratio gives an estimate of the correction of the optical beam in the direction of the reference object, i.e. as seen from the wavefront sensor in NAOS. Conversely, the off-axis Strehl ratio is computed from the estimated PSF on the science object, which allows one to estimate the correction provided by NAOS for the target.
- The full width at half-maximum of the PSF is given in arcsec both in the main panel and in the pop-up window depicted in Figure 9-6.
- Transmission to CONICA is expressed as a fraction of incoming light, at the observing wavelength.

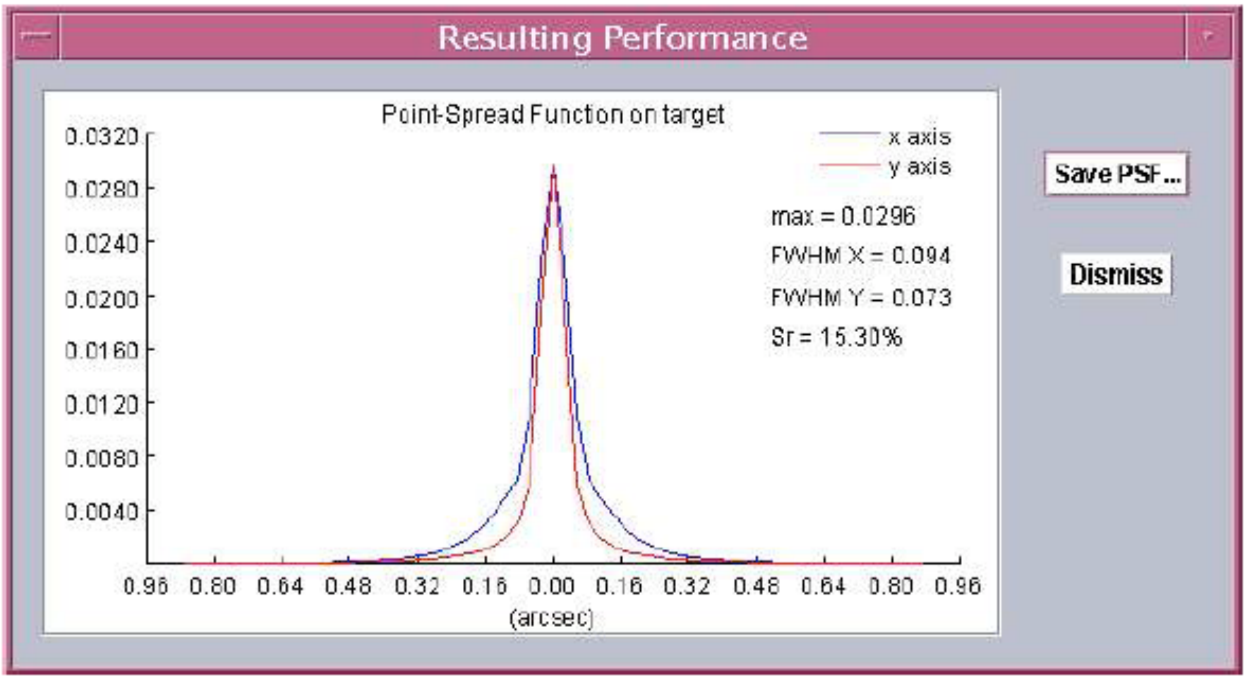


Figure 9-6: Pop-up window showing the PSF profile. This also gives access to the PSF FITS file. The different width of the PSF in x- and y-direction are due to anisoplanatism. The x-axis is here defined as the axis that is parallel to the line connecting the reference object with the science target.

9.5.6 Exporting to the Exposure Time Calculator

When clicking on Export to CONICA ETC at the bottom of the main panel, a file browser pops up. You can then give the name of an HTML file that will be created by the GUI and saved to your local disk. This HTML file contains the PSF profile, the CONICA filter and the magnitude and spectral type of the target.

To call the ETC, load this file into your favorite web browser and click on the Call CONICA ETC button at the bottom of the page.

9.5.7 Exporting to P2PP

All NaCo acquisition templates (Section 7.3) require a configuration file which is produced by the Export to P2PP button. It has the default extension aocfg and it is saved in the directory specified in the Preferences menu, under the option set the cache folder. This file contains all the information relevant to the setup of NAOS during acquisition of the target.

When preparing your observations with the PS and P2PP the following points should be noted:

- The output file is a text file, and it should never be manually edited. If you do, the execution of your OB will be seriously compromised.
- There must be one configuration file per target. The same configuration file cannot be used for different targets, but is fine for different OBs using the same target.
- The configuration file is inserted into the "NAOS parameter file" keyword of the relevant acquisition template.
- The Strehl, seeing and airmass constraints, and the RA and DEC fields of P2PP will be automatically filled when the configuration file is loaded. Do not edit these fields.

9.5.8 Exporting OBs from P2PP

The export facility in P2PP allows one to export observing blocks. For NaCo, two files are produced, one with the extension obx and another with the extension aocfg. These files should be kept in the same directory. P2PP will report an error if the two files are in different directories.

9.5.9 Saving/Restoring a PS Session

The complete PS session can be saved on local disk and restored. The Save Session and Load Session functions, available from the File menu of the main panel, allow you to save or load the corresponding information on your disk. Please be aware that loading a previously saved session file will discard all the data currently stored in the interface. However, it does not alter any of the configuration files that have been saved to disk. Only the files with an extension .jnps can be loaded into the PS. Once a previous session is loaded into the PS, one should run the optimization again before exporting to P2PP, otherwise a corrupted file may be exported and the observation may be impossible. In case one forgot to save a session, it is possible to copy the *.aocfg file into a *.jnps file and then import it as a session.

9.5.10 Giving names to session, P2PP and PSF files

Each time a file is about to be saved, one is asked to provide a name. The default name is based on the target name, but one may want to change it. This does not affect the operations, and may be convenient for the user. However, remember the files will be used by Unix-based machines, so one should avoid special characters - spaces, brackets, etc. - in the names.

9.5.11 User's preferences

The Preferences menu gives access to configurable functionalities of the PS, which are detailed below:

- Show tool tips: every field in the GUI has an attached tool tip. Though very useful when starting to use the PS, this may be annoying for more experienced users. This option allows one to switch them on/off.

- Set working directory: you can specify here the name of the directory where the output files are created by the PS (the one to be inserted in P2PP OBs) are saved. The default is your home directory.
- Set server name: this menu item raises a small pop-up window that allows one to change the name of the host machine where the PS server can be accessed. It is unlikely that normal users will need to use this feature. If you do happen to accidentally change the name, the server name can be found at

  http://www.eso.org/observing/etc/naosps/doc/.

Every change is automatically recorded in the .jnpscf file, located in the user's home directory. Additionally, depending on your local installation of the PS, you may want to edit the file and modify the web.enable resource, enabling you to switch between the standard installation (web.enable=true) and the case where you access the PS server on your local machine (web.enable=false). However, this latter case should normally never be encountered by the average user, hence the default value is the correct one in most cases.

10 APPENDIX - DPR KEYWORDS FOR NACO

Each template that collects data with NaCo, being it an acquisition template or a science or calibration one, writes a set of "HIERARCH ESO" header keywords that allows quick identification of the type of data. These keywords, commonly called DPR keywords, are three: CATG, which stays for category, TYPE and TECH, which indicates the observing technique.

CATG can be of type ACQUISITION, for acquisition images, CALIB for CALIBRATIO frames and SCIENCE. There are other types, such as TEST, which is normaly reserved for frames of no important content generated while testing.

TYPE can be DARK, FLAT,LAMP (internal lamp flat), WAVE, LAMP (internal lamp arc), SKY, OBJECT, PSF-CALIBRATOR, STD (for standard stars). Other values are possible, especially used for technical templates (such that for detector's tests).

TECH for NaCo has values, which are linked to the various observing modes. A combinations of keywords is usually necessary to give an accurate description of the technique: for instance, IMAGE, JITTER, SAM, PT, CUBE will describe SAM images with pupil tracking (PT) and CUBE mode active. DIFFERENTIAL is reserved for SDI+. All the other names are self explanatory.

These keywords can be used for images selection in the archive when one uses the NaCo dedicate query form available at: http://archive.eso.org/wdb/wdb/eso/naco/form

TPL.ID	DPR.CATG	DPR.TYPE	DPR.TECH	Notes
		Dark		
NACO_all_cal_Darks	CALIB	DARK	IMAGE	
		Acquisition		
NACO_img_acq_MoveToPixel	CALIB	PSF-CALIBRATOR	IMAGE	
NACO_img_acq_MoveToPixel	ACQUISITION	SKY	IMAGE	
NACO_img_acq_MoveToSlit	CALIB	PSF-CALIBRATOR	IMAGE	
NACO_img_acq_MoveToSli	ACQUISITION	SKY	IMAGE	
NACO_img_acq_MoveToMask	CALIB	PSF-CALIBRATOR	IMAGE	
NACO_img_acq_MoveToMask	ACQUISITION	SKY	IMAGE	
NACO_img_acq_MoveToMask	CALIB	FLAT, LAMP	CORONOGRAPHY	As of P82. Only masks on glass substrate
NACO_img_acq_Polarimetry	CALIB	PSF-CALIBRATOR	IMAGE	
NACO_img_acq_Polarimetry	ACQUISITION	SKY	IMAGE	
NACO_img_acq_Preset	CALIB	PSF-CALIBRATOR	IMAGE	Discontinued as of P81
NACO_img_acq_Preset	ACQUISITION	SKY	IMAGE	Discontinued as of P81
NACO_img_acq_SDIMoveToPixel	CALIB	PSF-CALIBRATOR	IMAGE	
NACO_img_acq_SDIMoveToPixel	ACQUISITION	SKY	IMAGE	
NACO_img_acq_SDIMoveToPixel	CALIB	FLAT, LAMP	IMAGE, DIFFERENTIAL	As of P82
NACO_img_acq_SDIMoveToMask	CALIB	PSF-CALIBRATOR	IMAGE	As of P81
NACO_img_acq_SDIMoveToMask	ACQUISITION	SKY	IMAGE	As of P81
NACO_img_acq_SDIMoveToMask	CALIB	FLAT, LAMP	SDI4	As of P81
NACO_img_acq_SAMMoveToPixel	CALIB	PSF-CALIBRATOR	IMAGE	As of P82
NACO_img_acq_SAMMoveToPixel	ACQUISITION	SKY	IMAGE	As of P82
		Observations Imaging		
NACO_img_obs_AutoJitter	SCIENCE	OBJECT	IMAGE, PRE	
NACO_img_obs_AutoJitter	SCIENCE	OBJECT	IMAGE, JITTER	
NACO_img_obs_AutoJitterOffset	SCIENCE	OBJECT	IMAGE, JITTER	Discontinued as of P81
NACO_img_obs_AutoJitterOffset	SCIENCE	SKY	IMAGE, JITTER	Discontinued as of P81
NACO_img_obs_GenericOffset	SCIENCE	OBJECT	IMAGE, JITTER	

TPL.ID	DPR.CATG	DPR.TYPE	DPR.TECH	Notes
NACO_img_obs_GenericOffset	SCIENCE	SKY	IMAGE, JITTER	
NACO_img_obs_FixedSkyOffset	SCIENCE	OBJECT	IMAGE, JITTER	
NACO_img_obs_FixedSkyOffset	SCIENCE	SKY	IMAGE, JITTER	
NACO_img_obs_AutoChopNod	SCIENCE	OBJECT	IMAGE, CHOPPING	
Calibration Imaging				
NACO_img_cal_LampFlats	CALIB	FLAT, LAMP	IMAGE	
NACO_img_cal_SkyFlats	CALIB	FLAT, SKY	IMAGE	
NACO_img_cal_TwFlats	CALIB	FLAT, SKY	IMAGE	
NACO_img_cal_StandardStar	CALIB	STD	IMAGE, JITTER	
NACO_img_cal_ChopStandardStar	CALIB	STD	IMAGE, CHOPPING	
NACO_img_cal_Strehl	CALIB	PSF-CALIBRATOR	IMAGE	
Calibration SDI				
NACO_sdi_cal_LampFlats	CALIB	FLAT, LAMP	IMAGE, DIFFERENTIAL	
NACO_sdi_cal_TwFlats	CALIB	FLAT, SKY	IMAGE, DIFFERENTIAL	
Observations SDI/SDI+				
NACO_sdi_obs_GenericOffset	SCIENCE	OBJECT	IMAGE, DIFFERENTIAL, JITTER	
NACO_sdi_obs_GenericOffset	SCIENCE	SKY	IMAGE, DIFFERENTIAL, JITTER	
Observations Coronagraphy				
NACO_coro_obs_Stare	SCIENCE	OBJECT	CORONOGRAPHY, JITTER	
NACO_coro_obs_Stare	SCIENCE	SKY	CORONOGRAPHY, JITTER	
NACO_coro_obs_AutoChopNod	SCIENCE	OBJECT	CORONOGRAPHY, CHOPPING	
Calibrations Coronagraphy				
NACO_coro_cal_StandardStar	CALIB	STD	CORONOGRAPHY, JITTER	
NACO_coro_cal_NightCalib	CALIB	FLAT, LAMP	CORONOGRAPHY	
Observations SDI+4				
NACO_sdi4_obs_Stare	SCIENCE	OBJECT	SDI4	As of P81
NACO_sdi4_obs_Stare	SCIENCE	SKY	SDI4	As of P81
Observation Polarimetry Wollaston				
NACO_pol_obs_GenericOffset	SCIENCE	OBJECT	POLARIMETRY, WOLLASTON, JITTER	
NACO_pol_obs_GenericOffset	SCIENCE	SKY	POLARIMETRY, WOLLASTON, JITTER	
NACO_pol_obs_AutoChopNod	SCIENCE	OBJECT	POLARIMETRY, WOLLASTON, CHOPPING	
Calibration Polarimetry Wollaston				
NACO_pol_cal_LampFlats	CALIB	FLAT, LAMP	POLARIMETRY, WOLLASTON	

TPL.ID	DPR.CATG	DPR.TYPE	DPR.TECH	Notes
NACO_img_cal_ChopStandardStar	CALIB	STD	POLARIMETRY, WOLLASTON, CHOPPING	
NACO_img_cal_StandardStar	CALIB	STD	POLARIMETRY, WOLLASTON, JITTER	
Observations FPI				
NACO_fpi_obs_GenericOffset	SCIENCE	OBJECT	IMAGE, FABRY-PEROT, JITTER	Not offered
NACO_fpi_obs_GenericOffset	SCIENCE	SKY	IMAGE, FABRY-PEROT, JITTER	Not offered
Calibration FPI				
NACO_fpi_cal_StandardStar	CALIB	STD	IMAGE, FABRY-PEROT, JITTER	Not offered
NACO_fpi_cal_LampFlats	CALIB	FLAT, LAMP	IMAGE, FABRY-PEROT	Not offered
NACO_fpi_cal_Arcs	CALIB	WAVE, LAMP	IMAGE, FABRY-PEROT	Not offered
Observations Polarimetry Wire Grid				
NACO_img_obs_AutoJitter	SCIENCE	OBJECT	POLARIMETRY, WIRE_GRID, JITTER	Discontinued as of P2
NACO_img_obs_AutoJitterOffset	SCIENCE	OBJECT	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_img_obs_AutoJitterOffset	SCIENCE	SKY	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_img_obs_GenericOffset	SCIENCE	OBJECT	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_img_obs_GenericOffset	SCIENCE	SKY	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_img_obs_FixedSkyOffset	SCIENCE	OBJECT	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_img_obs_FixedSkyOffset	SCIENCE	SKY	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_img_obs_AutoChopNod	SCIENCE	OBJECT	POLARIMETRY, WIRE_GRID, CHOPPING	Ditto
Calibrations Polarimetry Wire Grid				
NACO_pol_cal_LampFlats	CALIB	FLAT, LAMP	POLARIMETRY, WIRE_GRID	Ditto
NACO_pol_cal_StandardStar	CALIB	STD	POLARIMETRY, WIRE_GRID, JITTER	Ditto
NACO_pol_cal_ChopStandardStar	CALIB	STD	POLARIMETRY, WIRE_GRID, CHOPPING	Ditto
Observations Spectroscopy				
NACO_spec_obs_AutoNodOnSlit	SCIENCE	OBJECT	SPECTRUM, NODDING	
NACO_spec_obs_GenericOffset	SCIENCE	OBJECT	SPECTRUM, JITTER	
NACO_spec_obs_GenericOffset	SCIENCE	SKY	SPECTRUM, JITTER	
Calibrations Spectroscopy				
NACO_spec_cal_Arcs	CALIB	WAVE, LAMP	SPECTRUM	
NACO_spec_cal_LampFlats	CALIB	FLAT, LAMP	SPECTRUM	
NACO_spec_cal_StandardStar	CALIB	STD	SPECTRUM, NODDING	
Observations SAM				
NACO_sam_obs_GenericOffset	SCIENCE	OBJECT	IMAGE, JITTER, SAM, PT	As of P82
Templates using Cube mode				
NACO_img_obs_AutoJitter			Add "CUBE" to existing DPR.TECH	

NACO_sam_obs_GenericOffset NACO_img_obs_GenericOffset NACO_img_obs_FixedSkyOffset NACO_sdi_obs_GenericOffset NACO_sdi4_obs_Stare NACO_coro_obs_Astro NACO_coro_obs_Stare NACO_img_cal_StandardStar NACO_coro_cal_StandardStar				
Templates using Tracking mode				
NACO_img_obs_AutoJitter NACO_sam_obs_GenericOffset NACO_img_obs_GenericOffset NACO_img_obs_FixedSkyOffset NACO_sdi_obs_GenericOffset NACO_sdi4_obs_Stare NACO_coro_obs_Astro NACO_coro_obs_Stare NACO_img_cal_StandardStar NACO_coro_cal_StandardStar			Add "PT" to existing DPR.TECH	
Calibrations: Linearity/Gain				
NACO_img_cal_Linearity	CALIB	LAMP, LINEARITY	IMAGE	Flat
NACO_img_cal_Linearity	CALIB	OTHER, LINEARITY	IMAGE	Dark
NACO_img_cal_Linearity	CALIB	FLAT, LAMP, DETCHECK	IMAGE	Flat. As of p82
NACO_img_cal_Linearity	CALIB	DARK, DETCHECK	IMAGE	Dark. As of p82