VERY LARGE TELESCOPE

NAOS-CONICA User Manual

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Change Record

Issue/Rev.	Date	Section/Parag. affected	Reason/Initiation/Documents/Remarks
First issue	31 July 2001	all	new
Second issue	06 Aug. 2001	all	corr. just after PAE
Corrections	12 Oct. 2001	all	comments by AMO,RLE,ALA,DMO,FCO
Third issue	01 Mar. 2002	all	Comm 1 and 2 updates
1.4.1	05 Aug. 2002	all	Phase 2 P70 updates
1.4.2	01 Sep. 2002	all	Phase 1 P71 updates
1.4.3	17 Sep. 2002	5.10,5.11,6.2,6.9.4	Strehl Ratio Measurement
1.4.4	30 Nov. 2002	4.5.1,6.4,B	Minor corrections
1.5.0	22 Jan. 2003	all	Phase II P71 updates
1.5.1	31 Jan. 2003	Appendix B	Minor Corrections
1.5.2	12 Mar. 2003	1.2, 4.2, Tabs. 3, 17	P72 CfP
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1.7.1	01 Mar. 2004	1.3, 4.1.3, 4.2, 4.3	FPI, SDI and 4QPM added
1.7.2	01 Apr. 2004	4.1.3-5, 5.6, 5.8, 5.15 5.17, 6.4, 6.5.1-7 Tab. 15, 28, 29, Fig. 17	Template desc. for FPI and SDI added
1.7.3	19 May 2004	all	Correction of typos
1.8.0	19 June 2004	4.4.2, Fig. 6 4.6 6.2.1 Appendix B	new spec. modes with SL, SHK and prism Presentation of NEW CONICA detector special rotation template added New version of PS
2	23 Nov. 2004	1.1, 1.3 4.5, 4.5.1 6.2, 6.10.4 6.5.7	Update for P75 related to half-wave plate introduction of the half-wave plate introduction & definition of `NACO_pol_obs_Retarder` Wollaston_45 is now offered
3	16 May 2005	1.1, 5.14, 5.17, 6.10.4 Table 16	Update for P76 (related to HWP) Update of full well depth & minDIT
3	26 May 2005	4.2	Inserted an image of the SDI FOV
4	01 Sep. 2005	1.2, 1.3, 5.6 Tab. 9, 4.2, 5.6 all	Update for P77 correction of few typos
4	19 Dec. 2005	1.3, 6.11.3	Presenting new coro template
5	01 Mar. 2006	1.1, 1.3 3.4, 5.18	Update for P78 Introduction to LGSF

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Change Record - Cont'ed

Issue/Rev.	Date	Section/Parag. affected	Reason/Initiation/Documents/Remarks
78	12 Jun. 2006	1.3	Update of changes for P78
		4.3, 4.5	Adjustment of the performance quoted
		5.8, 5.9	Changes for Pre-Imaging
		5.11	Update for LGS-operation
		6.5.2-6.5.7, 6.6.2-6.6.3,6.7.2-6.7.3	Update of keywords
78	23 Jun. 2006	B.3, B.5	Update due to LGS mode in PS
		all	Typos
		1.1, 6.1	Update version & period number
		5.5	Adding a comment on FS limits'check
		5.9	Update for PRE_PSF imaging
		6.7.1	Explaining the FPI order parameter
		B.1	Specifying JNPS working platforms
		B.3	Clarifying parameters
79	01 Sep. 2006	1.1, 1.3, 6.1	Update version & period number
79	19 Dec. 2006	1.3	Introduce the PS A_V modification for phase II.
		B.5, B.5.1, B.5.2, B.6, B.8, B.9	Smoothing the english
		Fig. 23	Replaced by the newest panel version.
		B.5.3	Definition of the new PS A_V parameter
80	05 Mar. 2007	First page	Change version
		1.2, 1.3	Presentation of changes for P80
		4.2, 4.3	Update of new modes
		5.2	Update to suit the observatory calibration plan
		5.18	Corrected the time for LGS-pola ACQ
		5.19	Update after commissioning
81	24 Aug. 2007	First page	Change version
			Acronyms list
		1.2, 1.3	Presentation of changes for P81
		4.4, 4.4.1, 4.4.2	Update of new modes
		2.2.2, 4, 4.1.3, 5.6	Update of non-offered modes.
			Modified by: P. Amico
81.1	22 Dec. 2007	First page	Change version
		1,2,3,4,5	Included SDI+4, characterization of 4QPMs
		6, App. B	LGS guidelines, templates description
			Modified by: P. Amico

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Acronyms

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
CONICA	High Resolution IR Camera and Spectrometer
DPR	Data PRoduct
DIT	Detector Integration Time
DM	Deformable Mirror
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FLI	Fractional Lunar Illumination
FOV	Field of View
FP	Fabry-Perot
FS	Field Selector
FW	Full Well
FWHM	Full-Width at Half Maximum
GUI	Graphical User Interface
HWP	Half-Wave Plate
IB	Intermediate Band
IR	Infra-red
IRACE	Infra-red Array Control Electronics
LN2	Liquid Nitrogen
LW	Long Wavelength
M2	Secondary Mirror
NAOS	Nasmyth Adaptive Optics System
NB	Narrow Band
ND	Neutral Density
NDIT	Number of Detector Integration Time
NGS	Natural Guide Source
OB	Observation Block
P2PP	Phase 2 Proposal Preparation
PS	Preparation Software
PSO	Paranal Science Operations
PSF	Point-Spread Function
RON	Read Out Noise
RTC	Real-Time Computer
SDI	Simultaneous Differential Imager
SDI+	Simultaneous Differential Imager, larger FoV
SDI+4	Coronagraphy with 4QPM and Simultaneous Differential Imager
SM	Service Mode
SR	Strehl Ratio
SW	Short Wavelength
TTM	Tip-Tilt Mirror
VLT	Very Large Telescope
VM	Visitor Mode
WF	Wavefront
WFS	Wavefront Sensor

1   Introduction

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

NAOS (Sec. 3) is an Adaptive Optics (AO) system (section 2.1) that is designed to work with natural guide stars and extended objects. Provisions have been made for it to work with a laser guide star.

CONICA (Sec. 4) is an Infra-Red (IR) (1 − 5 μm) imager and spectrograph which is fed by NAOS. It is capable of imaging, long slit spectroscopy, coronographic and polarimetric observations with several different plate scales. The offered modes for period 79 are listed in Tab. 1.

NAOS-CONICA can be used in Service (SM) or Visitor Mode (VM). A number of calibrations are regularly performed by ESO for general use via the NAOS-CONICA Calibration Plan. Pipelines for quick look data reduction are available for some modes of the instrument.

Table 1: Main modes and parameters of NAOS-CONICA

Adaptive Optics Performance	40% Strehl ratio in K under median atmospheric conditions and with a reference object of V=10 mag or K=6 mag
Imaging	Broad- and narrow- band filters in the $1 - 5.0\mu m$ region with 14–56″ fields of view and 13–54 mas pixel scales Simultaneous Differential Imaging (SDI+, VM only).
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, together with 4 grisms of resolving power 400–1400
Polarimetry	Imaging with a Wollaston prism or wire grids

This manual is organized as follows. A brief summary of AO techniques and IR observations are given Sec. 2. NAOS is described in Sec. 3, CONICA in Sec. 4 and NAOS-CONICA operations in Sec. 5.

The templates, which are used to acquire and observe targets and to obtain calibrations, are described in Sec. 6. Readers of this manual are encouraged to read this section carefully.

Transmission curves of the filters are given in Appendix A and the Preparation Software (PS) is described in Appendix B.

Additional information can be found at the following URL addresses:

- NAOS-CONICA web pages: `http://www.eso.org/instruments/naco`

- NAOS-CONICA calibration plan: `http://www.eso.org/instruments/naco`

- Call for Proposals for information on how to submit a proposal for NAOS-CONICA: `http://www.eso.org/proposals`

- Exposure Time Calculator: `http://www.eso.org/observing/etc/`

- Catalogues for adaptive optics reference objects:
  Optical sources: GSC2 at ESO (skycat) — `http://archive.eso.org/skycat/` or GSC2 at STScI
  — `http://www-gsss.stsci.edu/`
  Infrared sources: `http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=2MASS`

- NAOS Preparation Software:
  `http://www.eso.org/observing/etc/naosps/doc/`

- Phase II Proposal Preparation:
  `http://www.eso.org/observing/p2pp`
  and notes relevant to NAOS-CONICA:
  `http://www.eso.org/observing/p2pp/NACO/NACO-P2PP.html`

- NACO Quality control: `http://www.eso.org/observing/dfo/quality`

Should you have any question regarding NAOS-CONICA operations, the point of contact is the User Support Department (usd-help@eso.org) in Garching.

1.1 Current version of this User Manual

This is version 81 of the NAOS-CONICA User Manual, applicable for phase I preparation for period 81. Since NAOS-CONICA is in constant improvement and modes are refined (especially the new ones), it is advisable to check the NAOS-CONICA web page for possible updates to this manual and for recent news.

1.2 Changes for period 81

The following changes are implemented for P81:

- In addition to the newly commissioned modes offered in P80, in P81 a new mode, which combines simultaneous differential imaging and coronagraphy (SDI+ with 4QPM optimized for H band, dubbed SDI+4), is offered in **VM only**. This mode is expected to improve the search for methane companions. like giant extrasolar planets around nearby stars.

- Fabry-Perot imaging is not offered.

- Chopping will not be supported in P81. All modes requiring chopping (imaging and polarimetry in M' and coronagraphy with LW filters) will not be offered.

- Coronagraphy with the semitransparent mask and the S13 camera is not recommended, since the spots are at the edge of the available field of view.

Valid changes introduced in P80:

- The 'old' 4QPM coronagraphic mask has been replaced by a new one, still optimised for K band but with a limited field of view of 13×13".

- A new 4QPM, optimised for H band observations has been installed. Its field of view is of 8×8".

- A new SDI mode is offered. It uses the same camera as the old one, still useable, but has a different achromatic double Wollaston and has a square field of view of 8×8" instead of 5×5".

2 Observing with Adaptive Optics in the Infrared

2.1 Adaptive Optics

2.1.1 Atmospheric turbulence

The VLT (Very Large Telescope) has a diffraction–limited resolution of $\lambda/D = 0.057$ arcsec at $\lambda = 2.2\mu$m. But the resolution is severely limited by atmospheric turbulence to $\lambda/r_0 \approx 0.7$ arcsec, 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 60cm at $2.2\,\mu$m.

The correlation time of the turbulence, τ_0, is related to r_0 and the speed at which the turbulent air travels. For a windspeed of 10 m/s the correlation time is of the order of 60ms at $2.2\,\mu$m.

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.

2.1.2 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 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. This 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 τ_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.
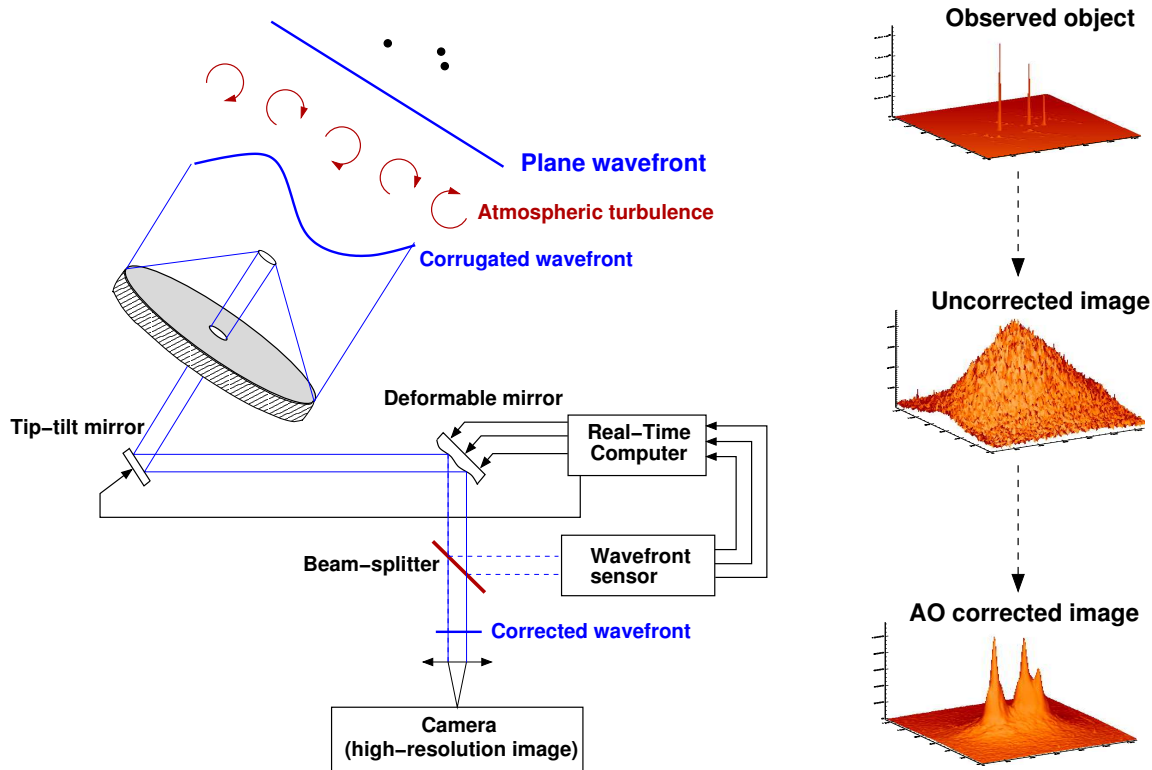
Figure 1: Principle of Adaptive Optics

2.2   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%) as 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 `NACO_img_obs_AutoJitter` template (Section 6.5.2) 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 L', 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 arc seconds, 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 typcial integration time and the typical amount of time between telescope offsets will be larger for CONICA.

2.2.1   Transmission and background

The transmission of the Earth's atmosphere in the 1–5μm region is shown in Fig. 2. The X, J, H, K, L and M bands correspond to atmospheric windows which are approximately centered 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.

In regards to observations with NAOS-CONICA, 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.

2.2.2   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 shortward of 4.2 microns and for regions that are relatively uncrowded (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 all the CONICA 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. 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 the NAOS-CONICA, the typical distance between the two positions (the chop throw) is 10 arcsec 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
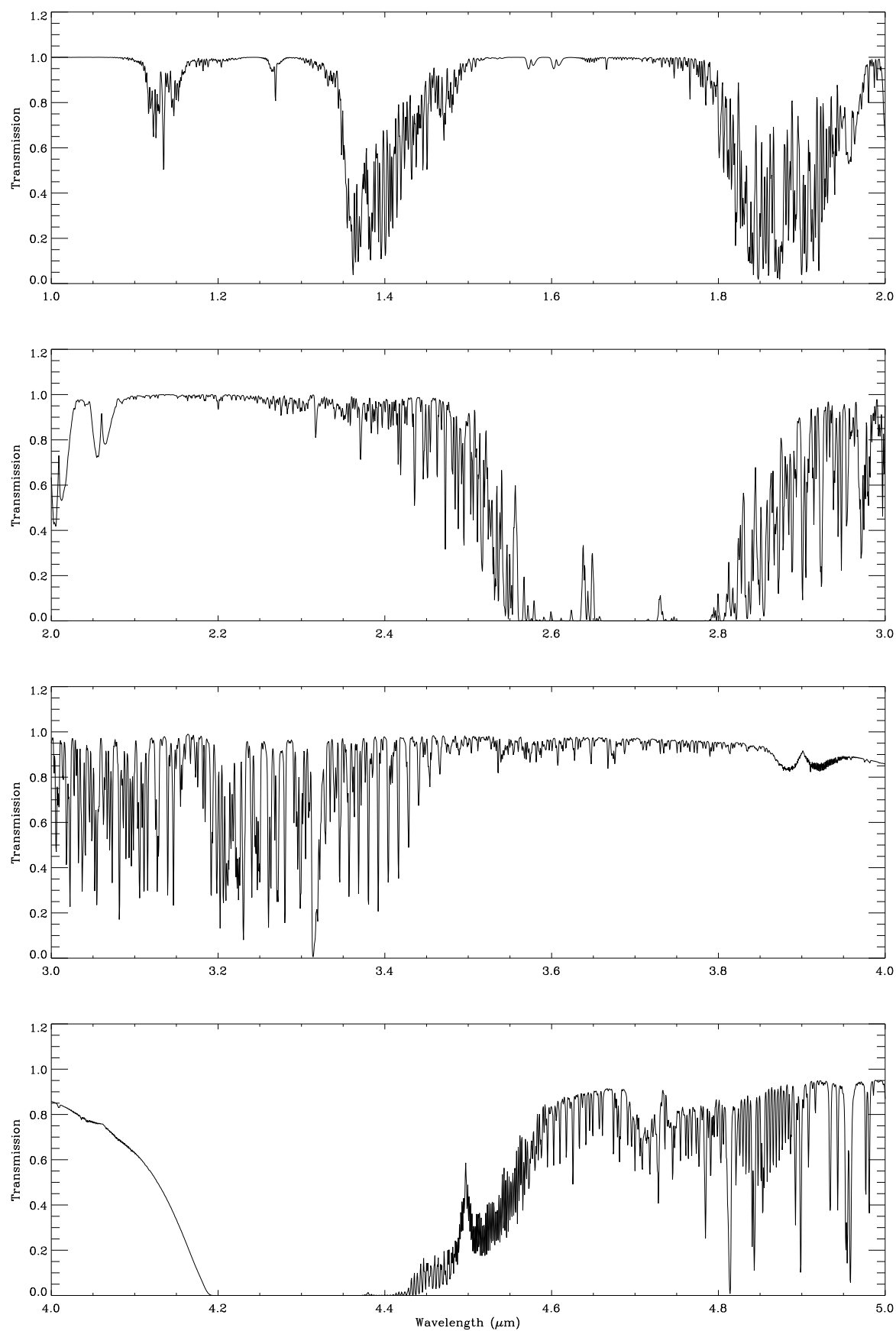
Figure 2: Model atmospheric transmission between 1 and 5 μm for a water vapour column density of 1.6mm and at airmass 1 (Lord 1992, NASA Tech. Mem. 103957)

has to work harder) and the residuals on the two sides of the nod are generally different. Consequently, they cannot be be perfectly removed.

For observations with NAOS-CONICA, 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 4.2μm, the sky is sampled frequently (i.e. **more** than once per minute) and **if** conditions are clear. But, for coronographic 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. Since chopping is not offered in P81, these observing modes will not be available.

2.2.3 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. This results in 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 an 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 spectrophotometric calibration.

3   NAOS

3.1   Overview

NAOS provides a turbulence-compensated f/15 beam and a 2 arcmin FOV to CONICA. Two off-axis parabolas reimage 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 3. The optical trains of the wavefront sensors are not shown in this figure.
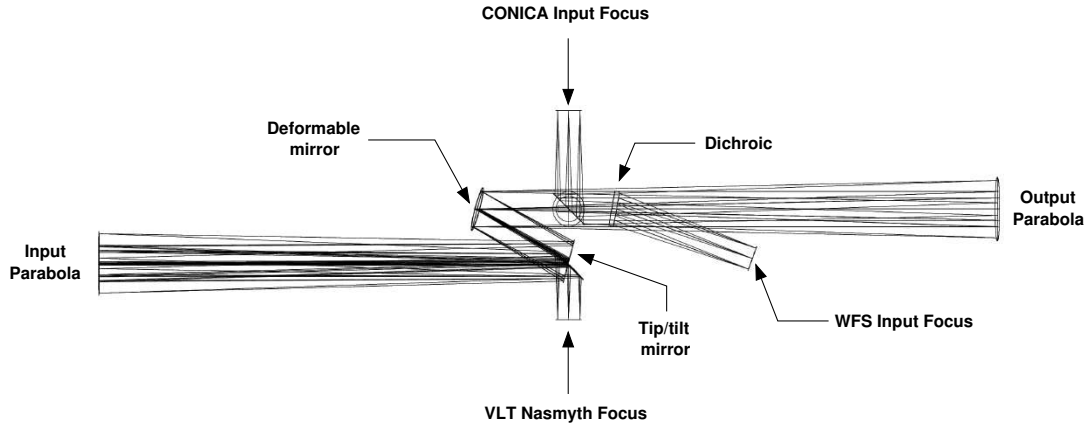
Figure 3: A view of the NAOS optical train.

The tip-tilt plane mirror (TTM) compensates for the overall WF tip and tilt, which are the largest disturbances generated by the turbulence. The DM, which contains 185 actuators, compensates for the higher order aberrations including the static aberrations of NAOS and CONICA.

Table 2: NAOS dichroics/beamsplitters

Dichroic Name	Reflected light to the WFS	Efficiency	Transmitted light to CONICA	Efficiency	Conditions of use
VIS	V,R,I $0.45 - 0.95\,\mu m$	90%	J, H, K, L, M $1.05 - 5.0\,\mu m$	90%	near-IR observations with optical WF sensing
N20C80	V,R,I,J,H,K $0.45 - 2.55\,\mu m$	20%	V, R, I, J, H, K $0.45 - 2.55\,\mu m$	80%	WF sensing and observing in the infrared
N90C10	V,R,I,J,H,K $0.45 - 2.55\,\mu m$	90%	V, R, I, J, H, K $0.45 - 2.55\,\mu m$	10%	WF sensing and observing in the infrared[1]
JHK	I,J,H,K $0.80 - 2.55\,\mu m$	90%	L, M $2.8 - 5.5\,\mu m$	90%	thermal-IR observations with WF sensing in the near-IR
K	K $1.9 - 2.55\,\mu m$	90%	V, R, I, J, H $0.45 - 1.8\,\mu m$	90%	J, H observations with WF sensing in K

[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 Tab. 2. Users are invited to study this table carefully.

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, precalibrated 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 arcsecond (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. The observation of very bright objects is possible with the visible WFS by using neutral density filters. Note that these neutral density filters are distincts from the neutral density filters of CONICA and are not selectable within the NAOS-PS software nor within P2PP.

The two WF sensors are Shack-Hartmann sensors. For the visible WFS, two Shack-Hartmann sensors 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 Shack-Hartmann sensors are available: a 14×14 lenslet array, with 144 valid sub-apertures and two 7×7 lenslet arrays, with 36 valid sub-apertures. Independent of which Shack-Hartmann sensor is 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 3.

Table 3: Wavefront sensors: characteristics

Characteristics	Visible WFS	Infrared WFS [1]
Wavelength range	$0.45 - 1.0 \, \mu$m	$0.8 - 2.5 \, \mu$m
14×14: FOV per lenslet	2.32 arcsec	5.15 arcsec
magnitude range (broadband)	0 – 12	4 – 9
7×7: FOV per lenslet	4.64 arcsec	4.8 and 5.15 arcsec
magnitude range	12 – 16.7	9 – 12
Detector	128×128 EEV CCD	1024×1024 Rockwell Hawaii

[1] With the N20C80 dichroic. The magnitude ranges with the N90C10 dichroic will be approximately 1.5 magnitudes fainter.

3.2 NAOS Performance

The level of the AO correction depends on a large number of factors, such as seeing, the speed of the turbulance, 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 Tab. 4. The preparation software (Sec. B) should be used for more detailed predictions and simulated PSFs.

3.3 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.

Table 4: 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 microns). 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	on-axis SR (0.8″)	SR at 30″ (0.8″)	on-axis SR (1.2″)	SR at 30″ (1.2″)
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: 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.

3.4   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. However, 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 (m $\sim$ 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 meager 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 ~ 0.55, 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 (m $\sim$ 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 are building the laser room, beam relay and launch telescope while MPE and MPIA provide the laser itself.

The PARSEC project is based on a 4W CW Sodium Laser (589 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, an mV $\approx$ 11 artificial star to guide the AO servo loop. More typically, the artificial guide star

is in the range mV ≈ 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 (Fig. 4). A custom-made single mode fibre carries the high laser power to the 50cm 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 beam accordingly.
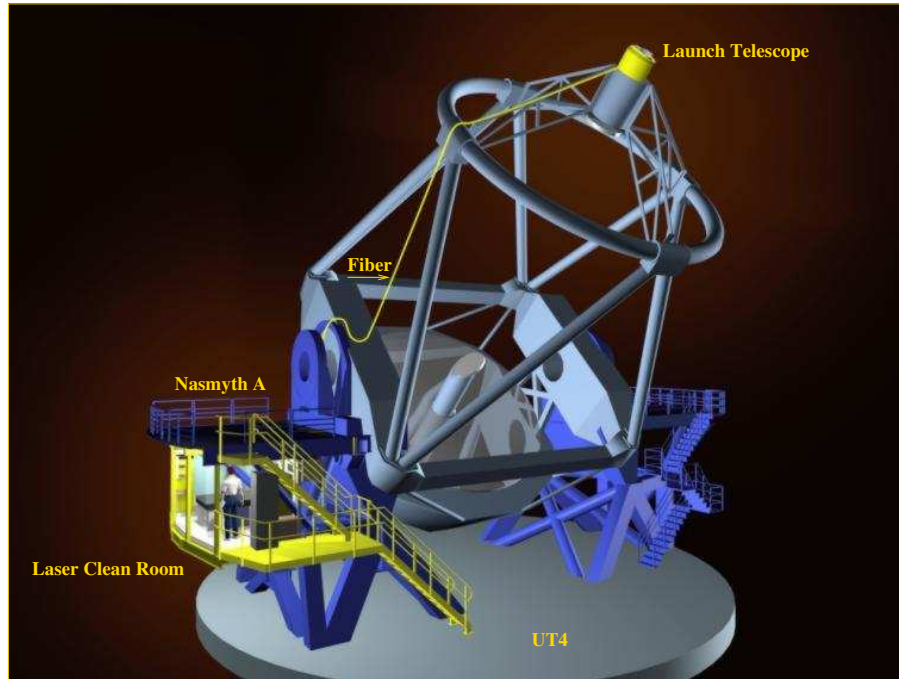
Figure 4: Illustration of the LGSF set-up at UT4: the laser clean room is installed below Nasmyth A. The laser beam is propagated via fiber to the launch telescope installed at the back of M2.

4 CONICA

CONICA is an IR $(1 - 5\,\mu\mathrm{m})$ imager and spectrograph, which is fed by NAOS. It is capable of imaging, long slit spectroscopy, coronagraphic and polarimetric observations with several different plate scales. This section describes the optical components of CONICA. See Fig. 5 for a drawing of the instrument.

The optical path includes the following components:

- the **slider** wheel, which is either open, 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.

- the **grism** wheel, which contains the grisms, the prism, the SDI and SDI+ wollastons, the wire grid analyzers for polarimetry and the J broad band 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 broad band filters (except J), the remaining NB filters, and the order sorting filters used in spectroscopy.

- the **camera** wheel, which contains all the objectives.

4.1 Imaging

Imaging is the simplest mode of CONICA. Images can be obtained with a variety of filters and pixel-scales.

4.1.1 Cameras

The characteristics of the cameras of CONICA are described in Table 5, in terms of plate scale and field-of-view (FOV). Each camera has a corresponding field mask which is automatically set by the instrument software.

4.1.2 Filters

All but one of the CONICA filters (Tables 6 and 7) are mounted on two filter wheels. Transmission curves, of several filters, are given in Appendix A. The J band filter is mounted on a third wheel which also contains the Wollaston prism and the wire grids, so J-band polarimetric observations are not possible with NAOS-CONICA.

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.
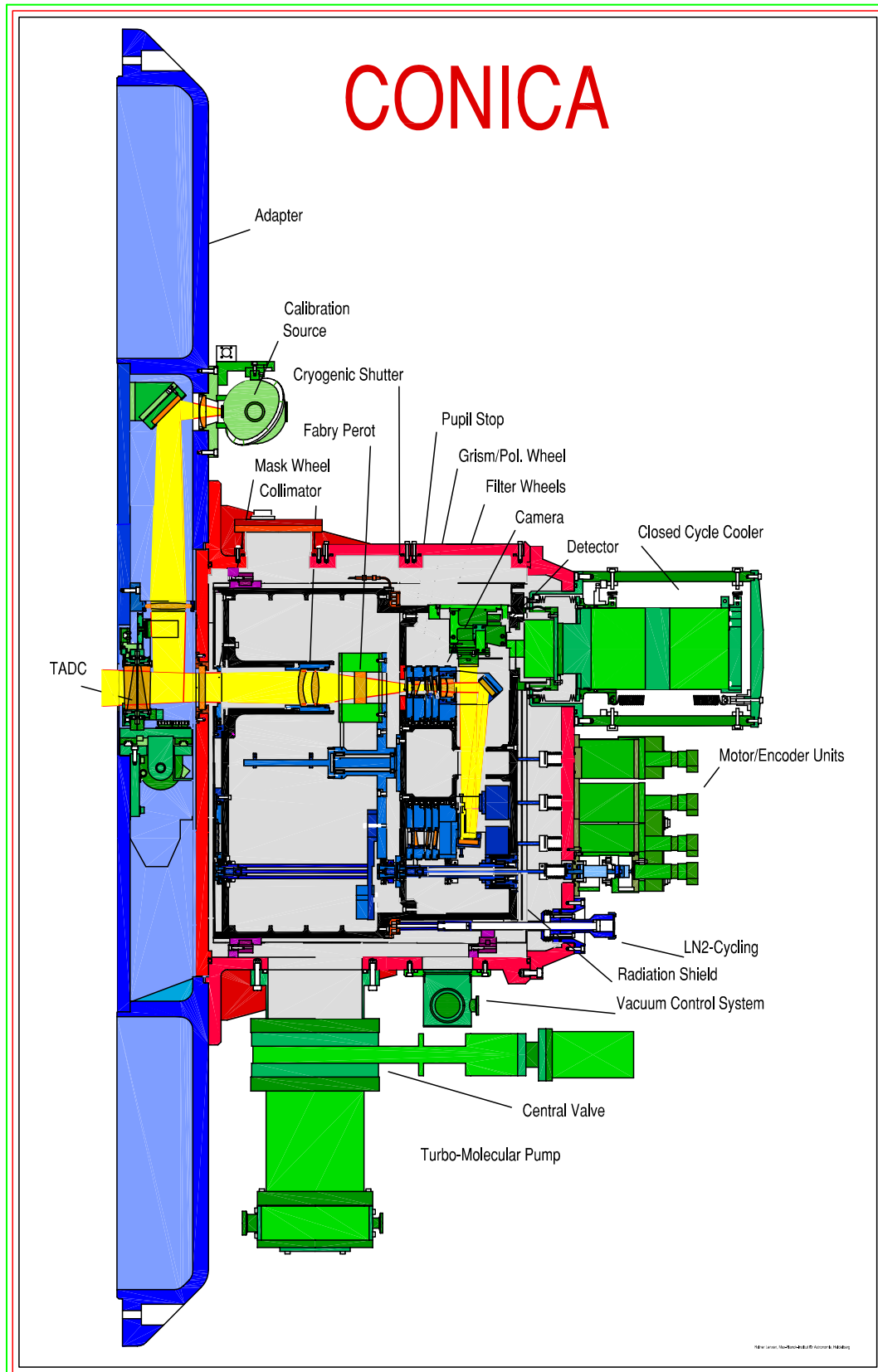
Figure 5: CONICA schematic overview

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

Camera	Scale [mas/pixel]	FOV [arcsec]	Spectral range
S13	13.27	14 x 14	1.0–2.5 μm
S27	27.15	28 x 28	1.0–2.5 μm
S54	54.6	56 x 56	1.0–2.5 μm
SDI[1]	17.32	5 x 5	1.6 μm
SDI+[1]	17.32	8 x 8	1.6 μm
L27	27.19	28 x 28	2.5–5.0 μm
L54	54.9	56 x 56	2.5–5.0 μm

[1] For imaging with the SDI mode only. See Sec. 4.2.

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, L' and M' filters can be used. For the L54 camera, only the NB_3.74 and NB_4.05 filters can be used.

Observations with the M' filter are restricted to a FOV of 14 arcsec × 14 arcsec. The FOV is smaller in M' than in other LW filters because the background in M' is considerably higher, and this means that the integration time has to be reduced which can only be done by windowing the array.

Additionally, there are two neutral density filters: ND_Long, which can only be used with LW filters and ND_Short which can only be used with SW filters. 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 are reduced by factors of 80 and 50 for the ND_Short and ND_Long filters respectively.

Table 6: List of CONICA broad-band imaging filters

Name	λ_c[μm]	FWHM[μm]	max. trans.
J	1.27	0.25	78%
H	1.66	0.33	77%
Ks	2.18	0.35	70%
L'	3.80	0.62	95%
M'	4.78	0.59	91%

4.1.3   Calibration plan

For imaging observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The what, when and how of calibrations is described in detail in the NACO Calibration Plan. http://www.eso.org/instruments/naos/index.html#Documentation.

- Nightly zero points (provided it is clear) in J, H and Ks with the S27 objective and visual dichroic. Zero points in L' and M' 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 L' and M' will be done in Uncorr. Zero points in all other filters (including the FP) 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%. Should users need higher accuracy,

Table 7: List of CONICA narrow and intermediate band filters

Name	$\lambda_c[\mu m]$	FWHM[μm]	max. trans.
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%

they should provide OBs that will be executed either immediately before or after their observations. In that case, 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 than have been taken since operations began.

- Twilight Flat Fields in all filters, with the exception of the FP. Observations in J, H and Ks will be taken with the detector in `Double_RdRstRd`, observations in M',L', 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 (including the FP), objectives and readout modes, with the exception of M', L', NB_3.74 and NB_4.05.

- Detector darks in all readout modes and DITs as required.

4.1.4   Pipeline

The `NACO_img_obs_AutoJitter`, `NACO_img_obs_AutoJitterOffset` and `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.

4.1.5   Fabry Perot Imager

In period 81 the Fabry-Perot imager is not offered.

4.2   Simultaneous Differential Imager

The SDI mode of CONICA obtains four images through three narrow band filters simultaneously. Two images are taken outside the $\approx 1.6 \mu m$ methane feature (at $1.575\,\mu m$ and $1.600\,\mu m$) and two images are taken inside the feature (both at $1.625\,\mu m$). All filters have a FWHM of 25 nm. The platescale of the SDI camera is 17.32 mas/pixel.

There are now two SDI modes, based on the same principle but with slight differences.

In the "classical" SDI mode, the beam splitting is done by a double calcite Wollaston. The second Wollaston is rotated by 45 deg relative to the first, resulting in a rhomboid distribution of the four sub-images on the detector. See the NAOS-CONICA web pages for an example. To avoid overlapping of the FOVs, a small 5x5 arcsec mask is placed into the entrance focal plane. Particular care was taken to minimize differential static aberrations between the four beams (< 10 nm RMS per Zernike mode), resulting in PSFs and speckle noise distributions that are almost identical.

The mask used to be tilted but this has been fixed in June 2005; so that the FOV is indeed 5x5" - untilted (See Fig. 6 for details). Please note that in Fig. 6, CONICA was not aligned. Please check regularly following webpage for the latest news and image of the SDI mask: http://www.eso.org/instruments/naco/news.html

The new SDI+ mode, is based on the same principle but the four images are placed on a square. The Field of View is bigger: 8×8". Please note that in the image Fig. 7, the alignment was not optimum. One aligns CONICA so that each square appears aligned with the rows and columns of CONICA; however the vertical vignetting will always remain; it cannot be suppressed due to physical limitation of the system. Please check http://www.eso.org/instruments/naco/inst/New_cfp81.html for details of performance of this new SDI mode, offered in visitor mode as of period 80.

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 a methane rich object ($T_{eff} < 1000$ K) can be obtained in 40 min with a signal-to-noise ratio of 6.

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

4.3   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. Three masks are available: two opaque masks with diameters of 0.7 and 1.4 arc seconds and a semi-transparent mask with a diameter of 0.7 arc seconds.
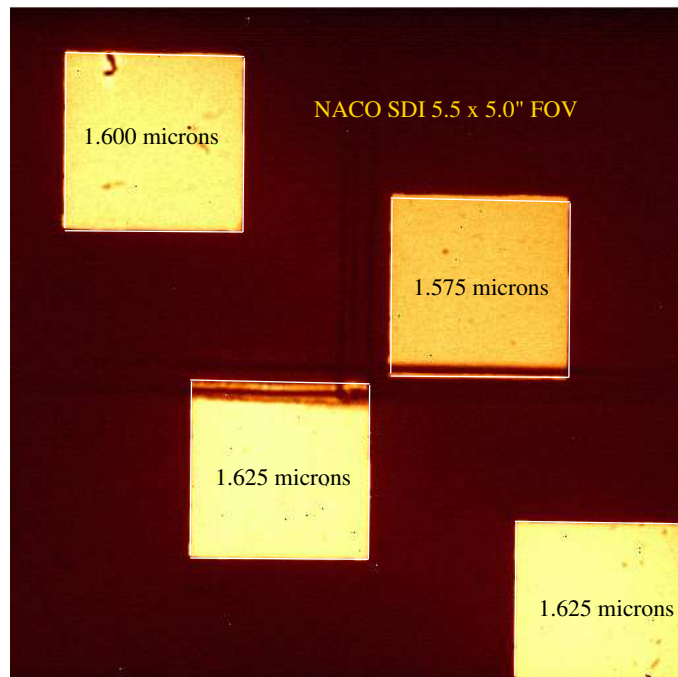
Figure 6: Flatfield image of the SDI mode. The transmitted wavelengths are indicated. Please note that on that image the mask was not centered.
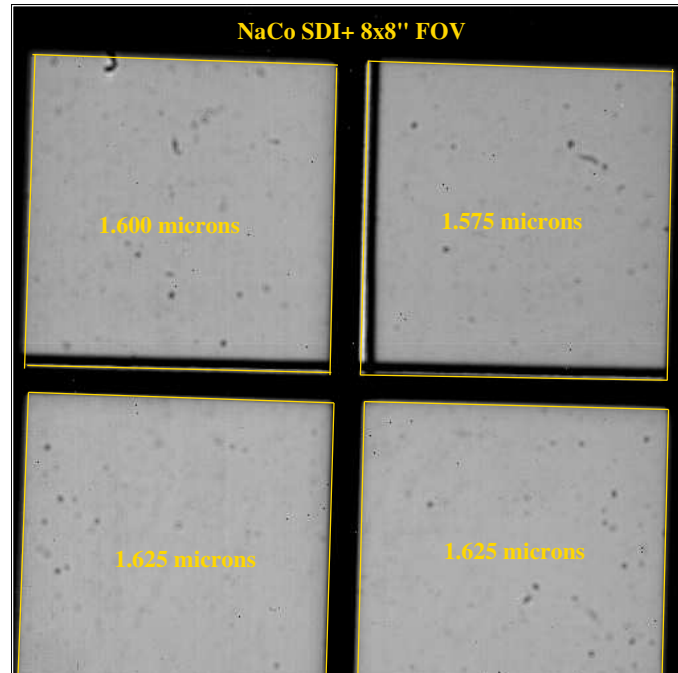
Figure 7: Flatfield image of the SDI+ mode. The transmitted wavelengths are indicated. Please note that on that image the mask is not well centered. However the vertical vignetting cannot be corrected for.
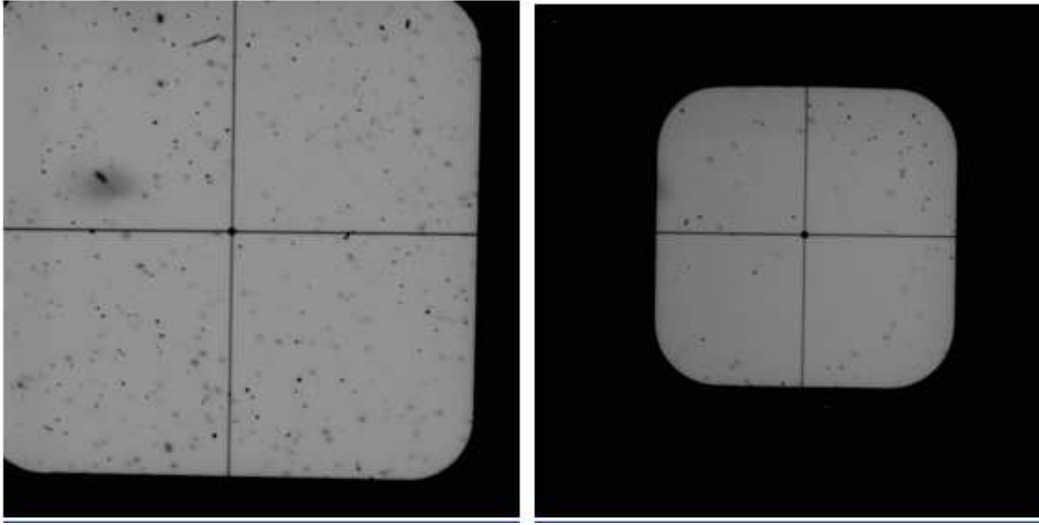
Figure 8: Flatfield image of the 4QPM_K + Ks filter (left) and of the 4QPM_H + H filter (right). The many dust particles observed in the flats generate flat-filed variations of 10-20% locally.

The contrast between inside and outside of the 0.7" semi-transparent mask has been measured to be ΔKs = 6.3 ± 0.1 and ΔH = 6.0 ± 0.1 (in Ks- and H-band respectively). The opaque masks are held by wires and the semi-transparent mask is situated on a transparent plate. The available masks are listed in Table 8.

More information on coronagraphy can be found at http://www.eso.org/instruments/naco/inst/corono.html

Table 8: Diameter, in arcsec, of the coronagraphic masks.

Name	Diameter	Comment
C_0.7	0.7	Opaque and held in place with wires 100% extinction over the mask
C_1.4	1.4	Opaque and held in place with wires 100% extinction over the mask
C_0.7_sep_10	0.7	Semi-transparent ($\approx 3.5 \times 10^{-3}$ transmissivity), situated on a glass plate.
4QPM-K	-	Four quadrant phase mask for K band (13×13" FOV)
4QPM-H	-	Four quadrant phase mask for H band (8×8" FOV)

In addition to the Lyot-style masks, there are two four quadrant phase masks (4QPM), which 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 split 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 center, 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 (Fig. 8) :

- 4QPM_H - optimized for a wavelength of $1.60\,\mu$m, circular field of view 8" diameter

- 4QPM_K - optimized for a wavelength of $2.18\,\mu$m, circular field of view 13" diameter.

These devices work best for filters that are centered at or near this wavelength.
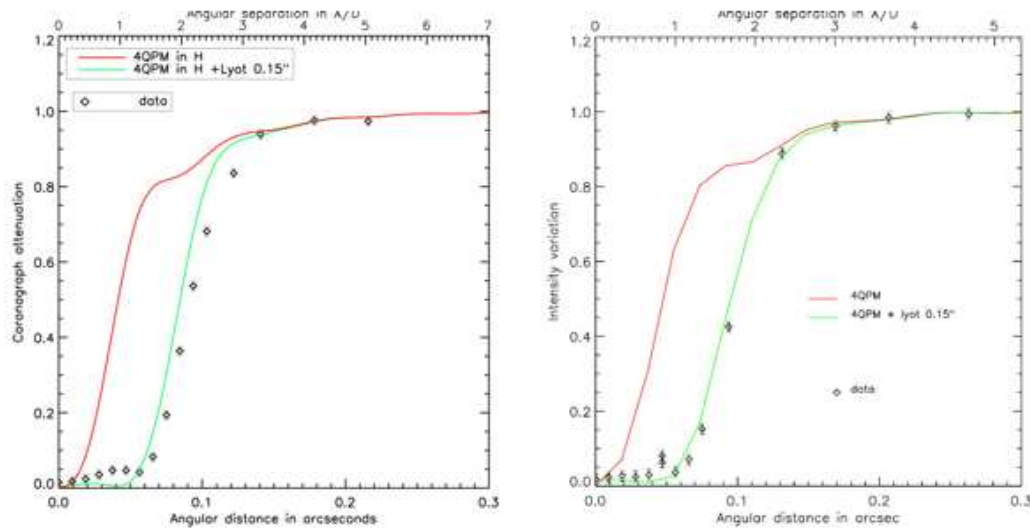
Figure 9: Radial attenuation of an off-axis point source moved outwards of the mask centre in H (left) and Ks (right). The data are shown as symbols and the lines are from simulations. Error bars correspond to the uncertainty in the intensity normalization with respect to the simulations.

4.3.1 Radial attenuation

The intensity of off-centered 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 9: these plots are important to correct the photometry of off-axis objects when looking at close companions for instance. For instance, a companion lying at 0.1 has its flux absorbed by 50% in the Ks band and 40% in the H band.

4.3.2 Contrast

Contrasts were measured on the PSF fiber for the 4QPM_K and the 4QPM_H. Azimuthally averaged radial profiles are shown in Figure 10 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.

4.3.3 Chromaticity

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 bean issue for NACO. Even with the fiber source, we observed very small variations as a function of the filter bandwidth as shown in Figure 11 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 broad band filters in the K band and respectively for the 4QPM designed for the H band.
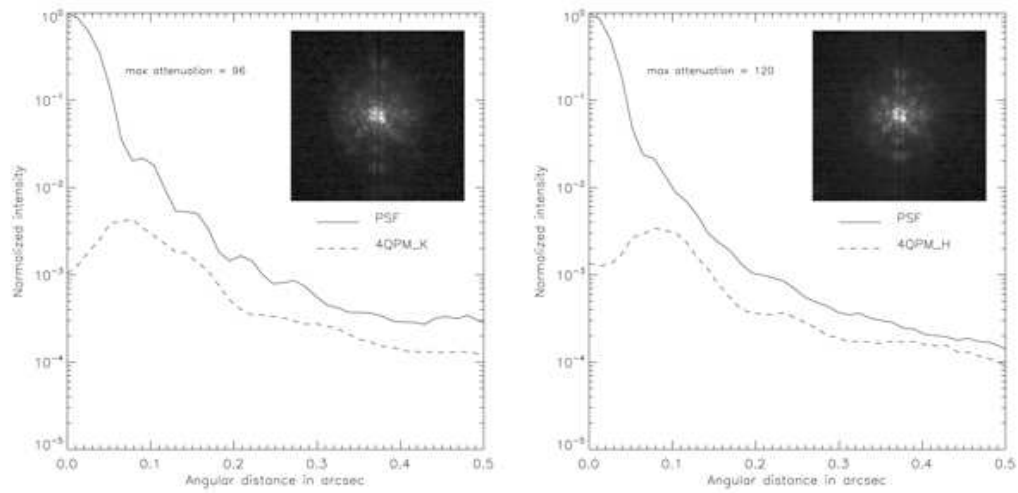
Figure 10: Radial profiles of the PSF compared to that of the coronagraphic image obtained with the 4QPM_K (left) and the 4QPM_H (right).
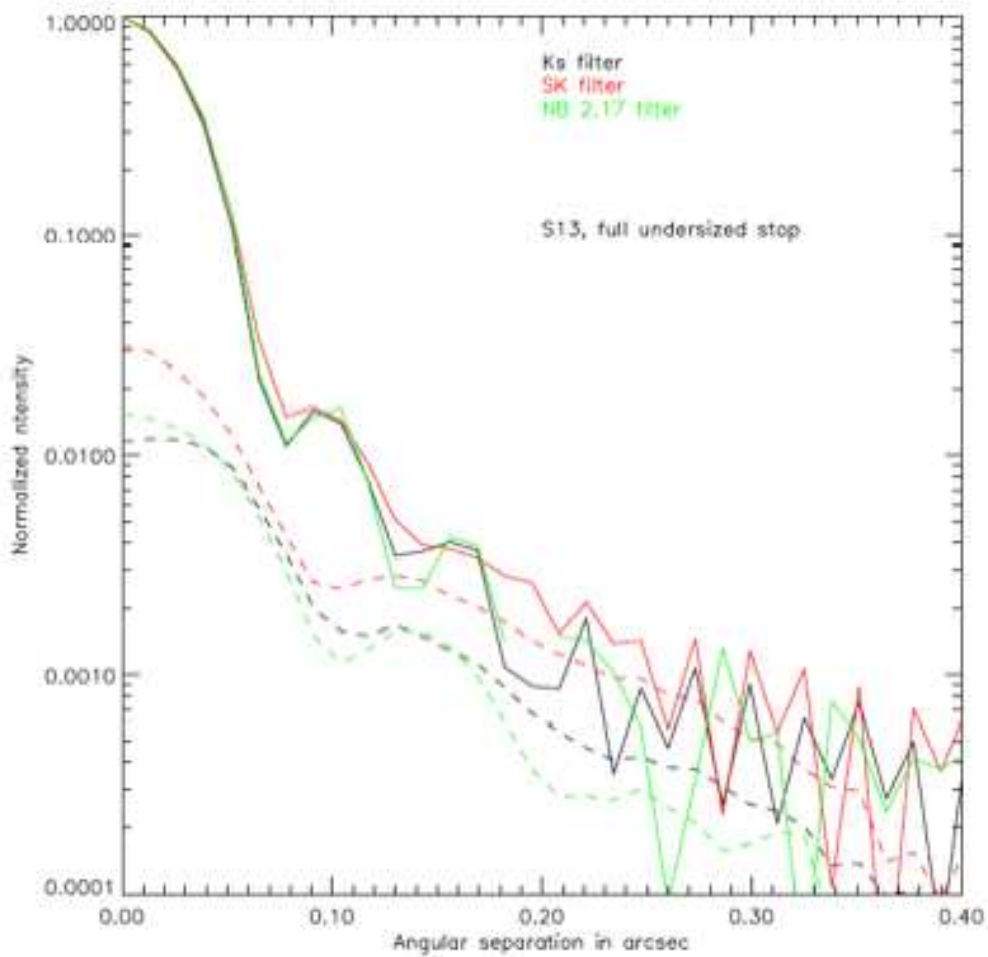
Figure 11: Chromaticity of the 4QPM_K measured on the 2004 mask with a fiber (i.e. no seeing effects).
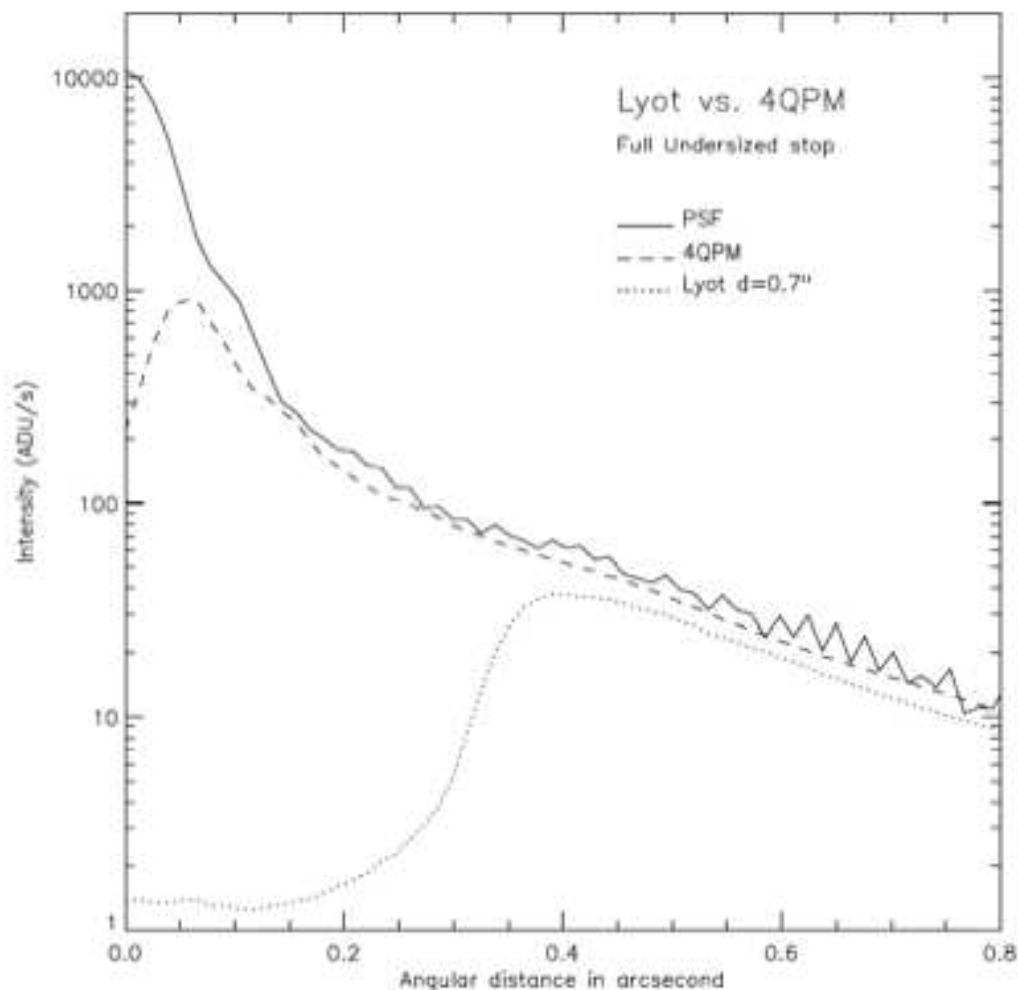
Figure 12: Radial profile for the PSF, the 4QPM and the 0.7" Lyot obtained with a natural star in 2004.

4.3.4 Comparison with the classic Lyot masks

Measurements were made in 2004 and are still valid for the new masks. Figure 12 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 thats precisely the interest of the 4QPM.

4.3.5 Observations strategy with 4QPMs

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

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

Coronagraphic images with 4QPM and broad band 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 optical aberrations along the optical train (from telescope to detector).

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 SNR in the image. More important, the reference **MUST** be observed with the same parallactic angle to have the same static speckle pattern (which result of 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 (reference is observed for the same amount of time as the target). In general, it is possible to found 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 9.5mag is achievable at 0.5 in H and Ks.

Other techniques involving field rotation (active or passive) can be envisaged but not tested yet.

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

Please refer to the webpage: http://www.eso.org/instruments/naco/inst/New_cfp81.html for more information.

4.3.6   Calibration plan

For coronagraphic observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The what, when and how of calibrations is described in detail in the NACO Calibration Plan. `http://www.eso.org/instruments/naos/index.html#Documentation`.

- Twilight flats and daytime lamp flats as described in Sec. 4.1.3. These calibrations are done without the focal plane masks.

- Detector darks in all readout modes and DITs.

4.3.7   Night flat fields

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 night time flat fields immediately after coronagraphic data have been taken. We strongly recommend that these calibrations are taken for the said masks. Night time 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 flatfielding 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.

4.3.8   Pipeline

Coronagraphic observations are not supported by the pipeline.

4.4   Simultaneous Differential Imaging plus coronagraphy

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).
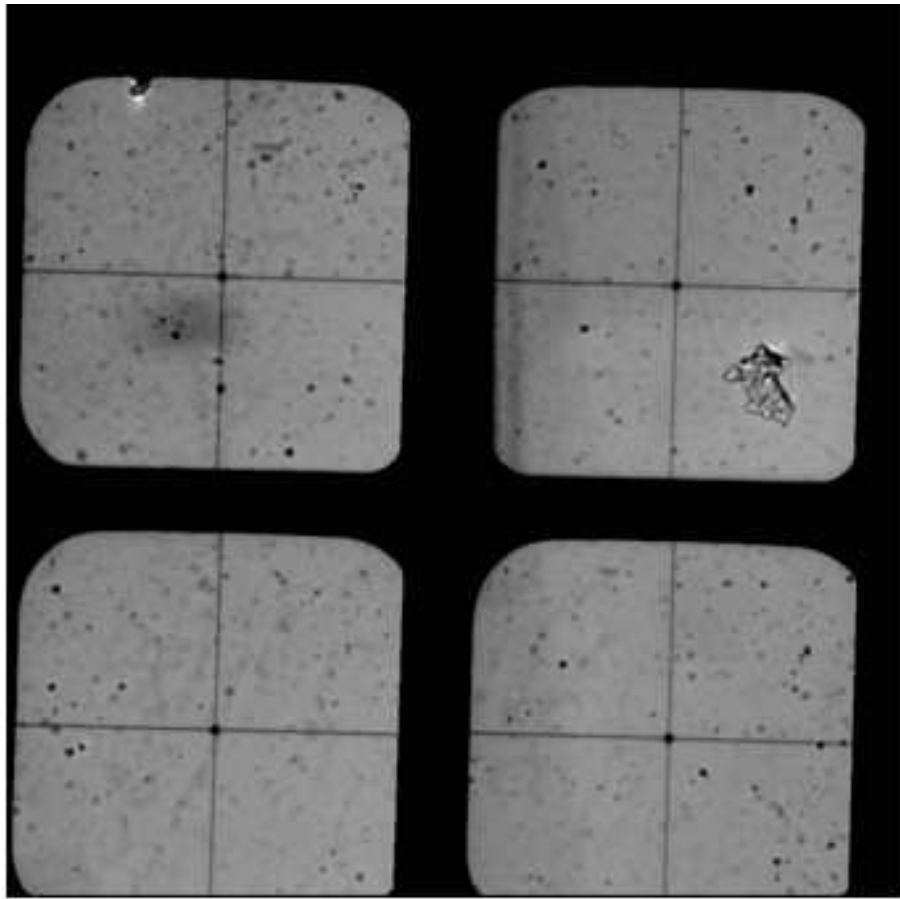
Figure 13: Flat field of the SDI+4, corrected from detector flat field taken with the H filter only (not SDI filters). The FoV is 8" for each quadrant.

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 substellar companions near bright stars, ideally down to massive EGPs, 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 to get closer to the central star.

An example flat field is shown in Figure 13.

This mode is now completely commissioned, and is offered in **VM only** as of P81. Please refer to the webpage: http://www.eso.org/instruments/naco/inst/sdi+4.html for additional information.

4.4.1 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-centered at the sub-pixels precision using the result of the Gaussian fitting. Sub-images were oversampled to improve alignment if needed and to allow better spectral rescaling.
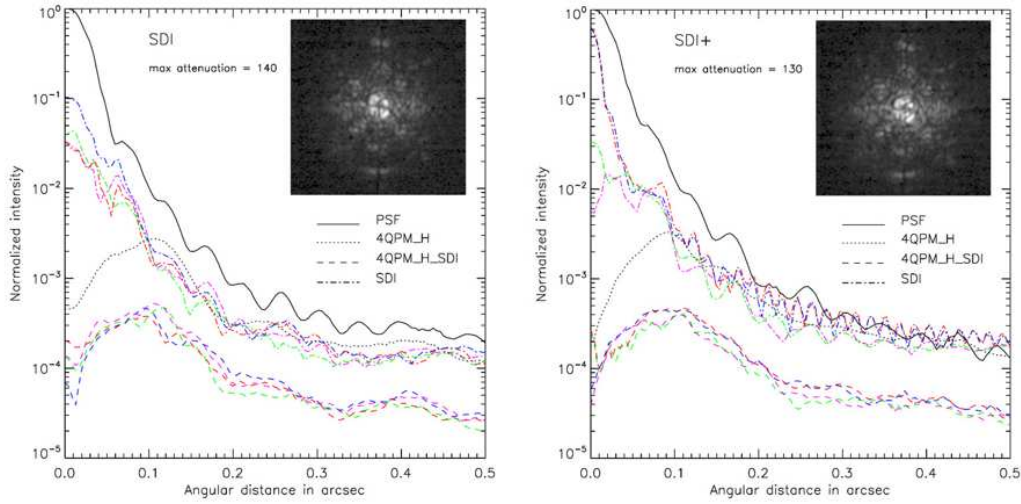
Figure 14: Radial profiles for the PSF (solid), the 4QPM image (dotted), and the SDI processing for PSFs (dash-dotted) and 4QPM images (dashed). Colors are for $\lambda_0 - \lambda_2$ (red), $\lambda_0 - \lambda_3$ (green), $\lambda_1 - \lambda_2$ (blue), $\lambda_1 - \lambda_3$ (purple). Left plot is for SDI and right plot is for SDI+.

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 **??**. The dotted line corresponding to the 4QPM alone is identical to Figure 10 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 deeper integration time are possible, the use of a coronagraph is known to be theoretically more favourable to differential imaging as demonstrated here.

4.4.2   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 15. 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 the figure, 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 arcsec and is the same further away. Roll averaging improves also the detection capability of the instrument (dashed red).

The standard SDI processing which consist in 2 observations at of 2 roll angles separated by 33° is also given in blue, but for 25° apart. This result 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
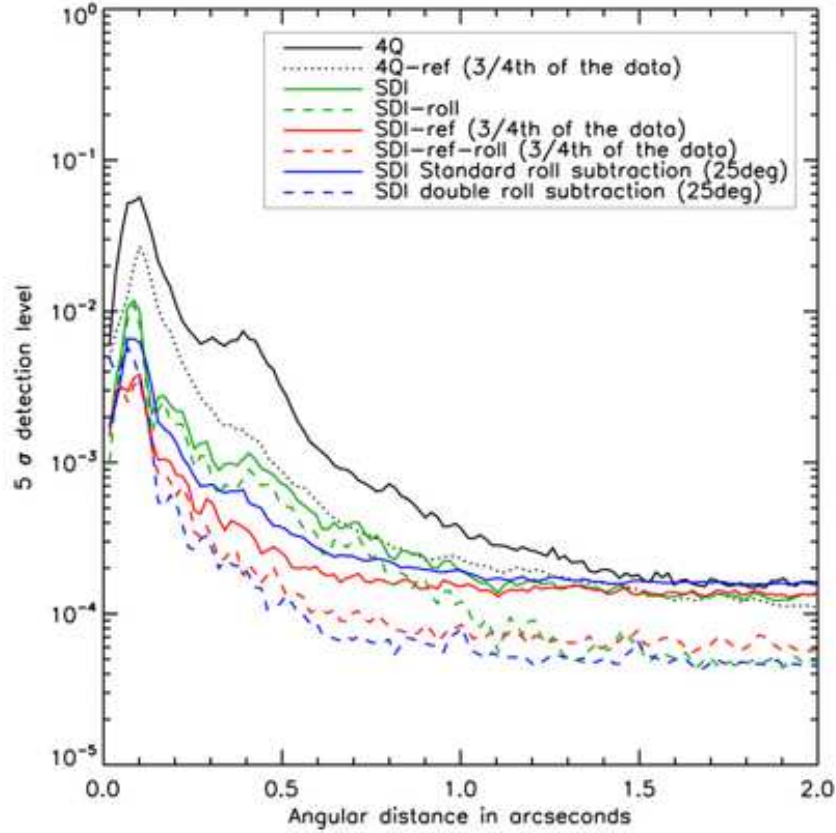
Figure 15: 5 σ detection level for different processing techniques. 4Q and 4Q-ref stand for direct corona-graphic imaging respectively not using and using reference subtraction. For all the lines that are called SDI, we are studying the spectral subtraction (image at $\lambda = 1.575\mu$m - image at $\lambda = 1.625\mu$). 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 $\lambda = 1.625\mu$)

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 25° :SDI(0°) -SDI(25°) and SDI(5°) - SDI(30°) and SDI(10°) - SDI(35°), etc up to SDI(25°) - SDI(50°). Adding them after having rotated them of 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 to the 5 images that have not been added yet (SDI(30°) to SDI(50°), note that they were used for subtraction though) the images that show an angle difference of -25°: SDI(50°) - SDI(25°) , SDI(45°) - SDI(20°), etc to SDI(30°) - SDI(5°). Adding all these roll subtracted images corrected from the instrument angle will create a typical spatial structure made of a positive PSF at the companion position and 2 negative PSF located at 25° on each side of the companion. The profile in Figure 15 clearly shows an improvement of about 1 mag with respect to standard SDI data reduction (SDI + 2 rolls).

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 25°, the PSF is attenuated by 20% at 150mas and less than 4% at 300 mas. The blue curve showed in Figure 15 has been corrected from 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 a SDI reference is better. However, since it does not use a reference image, the recorded time on the studied star is doubled for a given observing time. For this reason, we advise to record images with rotation steps of the instrument and use this double roll subtraction technique to improve at its best 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.

4.4.3   Calibration plan and night flats

The calibration plan does not support SDI+4.

4.4.4   Night flat fields

SDI+4 is 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 night time flat fields immediately after SDI+4 data have been taken. We strongly recommend that these calibrations are taken for the said setup. Night time flat fields with the fully opaque masks are not needed. These flats are taken without the mask.

4.4.5   Pipeline

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

4.5   Spectroscopy

Table 10 summarizes the main characteristics of the long slit spectroscopic modes.

4.5.1   Slits

Two long slits and a slitless mode are available for spectroscopy. The characteristics are listed in Tab. 9. 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 centering of the observed object in the slit (or to the center of the mask in the case of slitless spectroscopy) is done interactively through an acquisition template.

Table 9: Available slits in CONICA.

Name	Dimensions	Comments
Slit_86mas	86 mas x 40 arcsec	For S/L27 camera the slit length is 28 arcsec
Slit_172mas	172 mas x 40 arcsec	For S/L27 camera the slit length is 28 arcsec
Slitless	14 arcsec x 14 arcsec	For the SW spectroscopic modes only.

4.5.2   Spectroscopic modes

A spectroscopic mode is made up of a grism, an order sorting filter and an objective. Details of the offered spectroscopic modes are given in Table 10. The mode name is the identifier given to the mode and it is used in P2PP.

Moreover, a new prism with the capability of taking spectra over the 1- 5 micron range was inserted into the grism wheel. Three new spectroscopic modes with the new prism (See Table 11) have been defined. The spectral resolution varies from about 40, in the J-band, to 250, in the M-band.

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.

4.5.3   Calibration plan

For spectroscopic observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The what, when and how of calibrations is described in detail in the NACO Calibration Plan. `http://www.eso.org/instruments/naos/index.html#Documentation`.

- 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 catalog 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 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 86mas slit will be provided.

Table 10: Spectroscopic modes. The mode name consists of the objective, the grism number and the order sorting filter.

Mode Name [2]	Spectral domain (microns)	Order	Spatial Scale (mas/pixel)	Linear dispersion (nm/pixel)	R[3]
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[4]	2.60-4.20	2	54	3.16	700
L27_1_SL[4]	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

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

[2] 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 L'-filter.

[3] The resolution is computed for the 86mas slit. For slitless spectroscopy and for spectroscopy with the 172mas slit, the spectral resolution is set by the PSF.

[4] 3rd order overlap at 3.90 microns.

- Detector darks. Darks are taken at the end of each night with the `DITs` and readout modes used during the night.

Special note 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 and one for the L & M' calibration.

- 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 shortward of 4 microns to use this technique over the entire 1-5 micron wavelength range. However this remains to be tested.

Table 11: New spectroscopic modes

Mode Name	Filter	Dispersion (nm/pixel)	Wavelength Range	Resol.[1]	Fit Order	Fit RMS (nm)
L27_P1	None	8.5[2]	0.85-5.5	90	3	10
L27_P1	None	6.3[3]	0.85-5.5	250	5	2.9
S13_P1	CutOff_2.5um	4.1	0.85-2.50	60	3	10
S27_P1[4]	CutOff_2.5um	8.2	0.85-2.50	60	-	-

[1] Based on the 86mas slit and 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.

[4] Data for the S27_P1 mode has not been taken

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.

4.5.4 Night time 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 night time 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.

4.5.5 Pipeline

The spectroscopic mode of NAOS-CONICA is not supported by the pipeline.

4.6 Polarimetry

A Wollaston prism and four wire grids are 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. Thus 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. Thus, in a single exposure, at least half the field will be missing, so three exposures, with telescope offsets in between, are required to image one field. See Sec. 6.8.2. 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 separation for the different cameras are given in Table 12

The wavelength dependence of the beam separation shows that from 1 to 2.5μm the Wollaston prism can be used for broad band application without loss of spatial resolution. Within the K-band, for example, the

Table 12: Beam separation of the Wollaston-prism. The average beam separation corresponds to about 3.3 arcsec on the sky.

Camera	separation [pixel]
S13	254
S27	124
S54	62

resulting chromatic error is about 86mas.

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.

Four wire grid analysers (See Tab. 13) are mounted in the grism wheel. Unlike the Wollaston, the entire FOV is available. However, to obtain the Stokes parameters, an image with each of the analysers (hence four images in total) or with four different rotator angle or with 4 different angles of the half-wave plate is required.

Table 13: The names of the wire grid analysers and the angle at which they are mounted.

Name	Angle (degrees)
Pol_00	0
Pol_45	45
Pol_90	90
Pol_135	135

Since the J-band filter is in the same wheel as the Wollaston prisms and the wire grids, 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.

4.6.1 Calibration plan

For polarimetric observations, a variety of calibration frames will be taken, archived and updated at regular intervals. The what, when and how of calibrations is described in detail in the NACO Calibration Plan. `http://www.eso.org/instruments/naos/index.html#Documentation`.

- Twilight flats as described in Sec. 4.1.3. 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 4.1.3. 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. For polarimetric observations with the wire grids, flats with and without the polarizer are taken. There are no internal lamp flat calibration taken with the half-wave plate.

- Detector darks in all readout modes and DITs.

4.6.2   Pipeline

Polarimetric observations are not supported by the pipeline.

4.7   CONICA Detector

4.7.1   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 14.

Table 14: CONICA detector

Detector	Format (pixels)	Pixel Size (μm)	Dark current[1] (ADUs^{-1} pixel^{-1})	wavelength range (μm)	Q.E.
Aladdin 3	$1026^2 \times 1024$	27	0.05-0.15	0.8-5.5	0.8-0.9

[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, users will receive images that have 1024 pixels in x and y. For observations in the M-band, the array is windowed to 512×514.

The new detector is more sensitive to heavily saturated sources. The limiting magnitudes, that are observable, are specified in Table 19. Please check carefully section 5.15 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 Fig. 16.

4.7.2   `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` $\times$ `NDIT`).

4.7.3   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, eg. LW imaging. The minimum DIT without windowing is 0.1750 seconds. For observations in M′, the array is windowed to 512x514 and the minimum DIT is 0.0558 seconds.
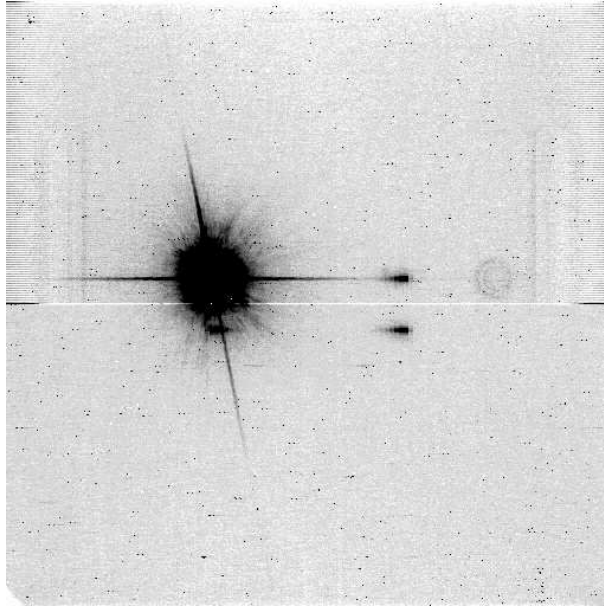
Figure 16: Illustration of the ghosts present on CONICA images when observing a bright object. In addition to the electronic ghosts, there is also an optical ghost characterised by its circular shape. The electronic noise visible on the sides of the array, as well as the 'bias' level of rows 512 & 512, disappear in the background subtraction.

- `Double_RdRstRd` - The array is read, reset and read again. It is used for situations when the background is intermediate between high and low. Eg. 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. Eg. 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 is 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 readnoise 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 15.

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 will only be 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. See Sec. 4.1.3, 4.6.1 and 4.3.6 for additional details.

Table 15: 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 [1] (ADU)	Min-DIT (sec.)
SW	FowlerNsamp[2]	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 L' imaging	Uncorr	HighWellDepth	4.4	9.8	22000	0.1750
LW M' imaging[3]	Uncorr	HighBackground	4.4	9.0	28000	0.0560

[1] This 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.

[2] 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.

[3] In M' imaging, the array is windowed.

5   Observing with NAOS-CONICA at the VLT

5.1   Overview

As with other ESO instruments, users prepare their observations with P2PP. Acquisitions, observations and calibrations are coded via templates (Sec. 6) 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 uses a grid of pre-defined setups; the user only specifies the usual parameters. 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. For phase II preparation, the HTML file produced by PS must be used.

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.

5.2   Visitor Mode Operations

Visitors arrive on Paranal 2 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 execution of their program is undertaken by the instrument operator.

Visitors should be aware that upto 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 taken usually involves 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 turbulance is fast.

5.3   Active optics and 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.

5.4   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 30° 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 30°). 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.

5.5   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 found 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 which results in the NAOS AO loop being closed at the end of the offset. The second is an offset which 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 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.

5.6 Chopping and Counter Chopping

Important: in P81 chopping is not supported

5.7 Target Acquisition

5.7.1 Imaging

Although the pointing accuracy of the VLT is very good, some of the CONICA fields-of-view are quite small. For the smaller fields-of-view (S13, S27 and L27), we recommend that users use the `NACO_img_acq_MoveToPixel` template. This template provides interactive tools like dragging arrows to define telescope offsets.

5.7.2 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 center objects into the selected slit which is overlaid on the 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 6.4.4. These instructions must be strictly adhered to.

5.7.3 Coronagraphy

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

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

5.7.4 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 center objects behind the 4QPM_H mask.

5.7.5 Polarimetry

For those OBs which use the Wollaston prism it is mandatory to use the `NACO_img_acq_Polarimetry` acquisition template and to use the same mask in both the acquisition and observing template(s)

This template provides interactive tools to center objects in the center of the selected mask which is overlaid on the RTD.

5.8 Pre-Imaging

As of P78, a "pre-imaging" mode is offered. It 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.

- to 2 imaging templates only: `NACO_img_obs_AutoJitter` & `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.

5.9 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 NAOS-CONICA requirements apply.

- The field of view of all finding charts must be 2' by 2' in size, with a clear indication of field orientation.

- 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 coronographic 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 coronography) or centered 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 centering 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 (or otherwise indicated on the Finding Charts). See Sec. 5.15 for the limits applied to service mode observations.

5.10   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 Period 78.

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.

5.11   Measuring the Strehl Ratio and OB Classification in Service Mode

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. In previous periods, we had asked users to include the `NACO_img_cal_Strehl` at the end of each OB. This template is no longer needed and it has been decommissioned.

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.

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 satisfactorally).

We are considering a similar classification scheme for the LGS-operation. Once completely decided a full update will be posted on the NaCo webpages: http://www.eso.org/instruments/naco/news.html.

5.11.1   PSF Reference Stars

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 NAOS-CONICA, 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.

5.12   Recommended `DIT`s and `NDIT`s

Unless the object is bright enough to cause saturation (See Tab. 15), `DIT`s need to be somewhat larger than those used in ISAAC, because the NAOS-CONICA 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 `DIT`s will have to be much smaller than the ones listed in Tab. 16. For `DIT`s larger than 60 seconds, users should consider using `FowlerNsamp` and not `Double_RdRstRd`. With `DIT`s larger than 60 seconds, the number of hot pixels in `Double_RdRstRd` is noticeably larger.

Table 16: Recommended `DIT` (in seconds) and `NDIT` ranges for NAOS-CONICA.

Filter	DIT (seconds)	DIT× NDIT(seconds)
J, SW NB filters and FP	60-300	120-300
H and Ks	20-120	60-240
LW NB filters	0.175-2.4	40-80
L' band	0.175	30
SW spectroscopy	60-900	120-900
LW spectroscopy	0.4-3.0	60-120

For observations that use chopping, `DIT` and `NDIT` are computed automatically by the templates.

5.13   IR backgrounds

Backgrounds are a function of the filter and the dichroic. They are listed in Tab. 17.

Table 17: IR backgrounds. The hyphens mark invalid combinations (NAOS dichroic + CONICA filter).

Filter	Background mag./sq. arc second				
	VIS	N20C80	N90C10	JHK	K
J	15.8	15.8	15.8	-	15.8
H	14.0	14.0	14.0	-	14.0
Ks	12.8	12.5	11.0	-	-
L'	3.0	-	-	3.0	-
M'	-0.5	-	-	-0.5	-

Users should note that the RON of the array can dominate if `DIT` is too small.

5.14   Recommended Magnitude Ranges for Standard Stars

The recommended magnitude range for standard stars in imaging and spectroscopy is given in Table 18. 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 18: 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 L' band	7-9
LW M' band	6-8
LW NB filters	4-6
SW spectroscopy	6-9
LW spectroscopy	4.5-6

5.15   Maximum Brightness of Observable Targets

Bright targets leave residual images that can take several minutes to disappear. The table below presents the absolute limits acceptable.

Table 19: Magnitude limits for `DIT` < 1.

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.

These limits apply for `DIT` < 1. Such bright objects heavily saturate the detector and cannot be used for science. For longer `DIT`s, 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 15).

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 seeked 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.

5.16   Night time calibrations

For spectroscopic observations, users can take spectroscopic flats and arcs immediately after the observation. These night time 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 inhomogenities 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 coronographic observations with the semi-transparent mask, users should take night time flats with the `NACO_coro_cal_NightCalib` template. These night time calibrations are sigificantly 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.

For FP imaging, we recommend that users do a scan of one of the bright argon arc lines with the `NACO_fpi_cal_Arcs` template immediately after the observations.

5.17   Pipelines

It is our long term aim to produce pipelines that reduce NAOS-CONICA data accurately. At this point in time, this is not the case and experienced observers will be able to do better than the pipeline. Thus we recommend that users only use pipeline products as a means of quickly assessing the data.

For the templates supported by the pipeline (currently, only imaging templates are supported), service observers will receive pipeline reduced data. Visitors will have direct access to the data processed automatically on line, but the data are not calibrated (e.g. flat fielded) as they are in Garching for service observations. Visitors can save the pipeline reduced data for themselves. Pipeline reduced data are not part of the data package they receive at the end of their run.

5.18   Instrument and Telescope Overheads

The execution time report produced by P2PP computes the overheads according to the rules reported in Table 20. 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 (Tables 21 to 31) 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.

5.19   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 which can take advantage of moderate Strehl ratios ("seeing enhancements") to achieve their scientific goals. From the past commissionning experience, one advises to avoid LGS observations for objects below airmass 1.5, for which the AO correction degrades strongly.

Due to the tip-tilt indetermination (see Section 3.4), 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 (45% against 60% 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 mV=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 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 20: Overheads

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

Table 21: Overheads – 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 seconds
NDIT	20
Number of offset positions	60
NEXPO per offset position	1
Readout mode	`FowlerNsamp`
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	10 minutes
Imaging acquisition	0.5 minutes
Sub-total (Acquisition)	16.25 minutes
Observation[1] = 60 * (27 + 20 * (3 + 2))	127 minutes
Total	145 minutes
Overheads	141%

[1]Observation = `Number of offset positions` × (Offset overhead + NDIT × (DIT + readout overhead))

Table 22: Overheads – Example 2 – Imaging a bright source (V=11 with the visual 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 seconds
NDIT	30
Number of offset positions	20
NEXPO per offset position	3
Readout mode	`Double_RdRstRd`
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
Imaging acquisition	0.5 minutes
Sub-total	11.25 minutes
Observation[1] = 20*(27 + 2 * 16 + 3*(30 * 2 + 0.7))	80.3 minutes
Total	91.6 minutes
Overheads	53%

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

Table 23: Overheads – Example 3 – Imaging a bright source in the L band (V=11 for visual WFS or K=7 for IR WFS) with `Uncorr`

Template parameters	
Acquisition Template	`NACO_img_acq_MoveToPixel`
Observation Template	`NACO_img_obs_AutoJitter`
DIT	0.2 seconds
NDIT	150
Number of offset positions	120
NEXPO per offset position	1
Readout mode	`Uncorr`
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
Imaging acquisition	0.5 minutes
Sub-total	11.25 minutes
Observation[1] = 120*(27 + 150 * 0.2)	114 minutes
Total	125 minutes
Overheads	108%

[1]Observation = `Number of offset positions` $\times$ (Offset overhead + `DIT` $\times$ `NDIT`)

Table 24: Overheads – Example 4 – Spectroscopy of a faint source with `FowlerNsamp`

Template parameters	
Acquisition Template	`NACO_img_acq_MoveToSlit`
Observation Template	`NACO_spec_obs_AutoNodOnSlit`
DIT	300 seconds
NDIT	1
Number of AB or BA cycles	6
NEXPO per offset position	1
Readout mode	`FowlerNsamp`
Return to Origin ? (T/F)	T
Jitter Box Width	10
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	10 minutes
Spectroscopic acquisition	5 minutes
Through Slit	2 minutes
Sub-total	22.75 minutes
Observation[1] = 2 * 6 * (27 + 300 + 2)	65.8 minutes
Total	88.6 minutes
Overheads	48%

[1]Observation = $2 \times$ `Number of AB or BA cycles` $\times$ (Offset Overhead + `DIT` + readout overhead)

Table 25: Overheads – Example 5 – Polarimetry of a bright source with the Wollaston.

Template parameters	
Acquisition Template	`NACO_img_acq_Polarimetry`
Observation Template	`NACO_pol_obs_GenericOffset`
`DIT`	10 seconds
`NDIT`	6
`Number of offset positions`	5
`NEXPO per offset position`	1
Readout mode	`FowlerNsamp`
`List of Position Angle Offsets`	0 45
`Return to the Original Rotator Position?  (T/F)`	F
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
Polarimetric acquisition	1 minute
Sub-total	11.75 minutes
Observation at 0 degrees[1] = 5*(27 + 6 * (10+2))	8.3 minutes
Rotator offset	1 minute
Observation at 45 degrees = 5*(27 + 6 * (10+2))	8.3 minutes
Total	29.35 minutes
Overheads	193.5%

[1] Observation = `Number of offset positions` $\times$ (Offset overhead + `NDIT` $\times$ (`DIT` + readout overhead))

Table 26: Overheads – Example 5b – Polarimetry of a bright source with the Wollaston & HWP.

Template parameters	
Acquisition Template	`NACO_img_acq_Polarimetry`
Observation Template	`NACO_pol_obs_Retarder`
DIT	10 seconds
NDIT	6
Number of offset positions	5
NEXPO per offset position	1
Readout mode	FowlerNsamp
List of HWP Angle offsets	0 22.5
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
Setting the HWP in/out[1]	1 minute
AO acquisition	5 minutes
Polarimetric acquisition	1 minute
Sub-total	12.75 minutes
Observation at 0 degrees[2] = 5*(27 + 6 * (10+2))	8.3 minutes
HWP rotation	0.25 minutes
Observation at 45 degrees = 5*(27 + 6 * (10+2))	8.3 minutes
Total	29.6 minutes
Overheads	196%

[1] At the beginning of each template the HWP is set into the beam and then moved away at the end, producing an extra 1 minute overhead per template.

[2] Observation = `Number of offset positions` $\times$ (Offset overhead + `NDIT` $\times$ (DIT + readout overhead))

Table 27: Overheads – Example 6 – SW Coronography of a bright source with `Double_RdRstRd`

Template parameters	
Acquisition Template	`NACO_img_acq_MoveToMask`
Observation Template	`NACO_coro_obs_Stare`
`Number of AB cycles`	2
`DIT`	10 seconds
`NDIT for the OBJECT positions`	6
`Number of Exposures (Object Only)`	10
`NDIT for the SKY positions`	5
`Number of offset positions (Sky only)`	4
Readout Mode	`Double_RdRstRd`
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
Coronographic acquisition	2 minutes
Sub-total	12.75 minutes
Observation[1] = 2 * (10 * (6 * 10 + 0.7) + 9 * 16 + 27 + 4 * (5 * 10 + 0.7 + 27))	36 minutes
Total	49 minutes
Overheads	84%

[1]Observation = `Number of AB cycles` × (`Number of Exposures (Object Only)` × (`DIT` × `NDIT` + readout overhead) + (`Number of Exposures (Object Only)` - 1) × time between frames without offsets) + Offset overhead) + `Number of offset positions (Sky only)` × (`DIT` × `NDIT` + readout overhead + Offset overhead))

Table 28: Overheads – Example 7 – LW Coronography of a bright source.

Template parameters	
Acquisition Template	`NACO_img_acq_MoveToMask`
Observation Template	`NACO_coro_obs_AutoChopNod`
`Integration time (minutes)`	20 minutes
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
Coronographic acquisition	2 minutes
Sub-total	12.75 minutes
Observation[1] = 20 * (1.3 * 60 + 27)	35 minutes
Total	48 minutes
Overheads	140%

[1]Observation = `Integration time (minutes)` × ((1 + 30%) × 60 seconds + Offset overhead)

Table 29: Overheads – Example 8 – Imaging with chopping.

Template parameters	
Acquisition Template	`NACO_img_acq_MoveToPixel`
Observation Template	`NACO_img_obs_AutoChopNod`
`Integration time (minutes)`	20 minutes
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
Imaging acquisition	0.5 minutes
Sub-total	11.25 minutes
Observation[1] = 20 * (1.3 * 60 + 27)	35 minutes
Total	46 minutes
Overheads	130%

[1]Observation = `Integration time (minutes)` $\times ((1 + 30\%) \times 60$ seconds + Offset overhead)

Table 30: Overheads – Example 9 – Imaging a faint source with the FP.

Template parameters	
Acquisition Template	`NACO_img_acq_MoveToPixel`
Observation Template	`NACO_fpi_obs_GenericOffset`
`DIT`	60 seconds
`NDIT`	1
`Number of offset positions`	10
`NEXPO per offset position`	1
`Readout mode`	`FowlerNsamp`
`Wavelength list`	5 settings
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	10 minutes
Imaging acquisition	0.5 minutes
Sub-total (Acquisition)	16.25 minutes
Observation[1] = 10 * (13 + 5 * (60 + 2 + 10 + 16))	75.5 minutes
Total	92 minutes
Overheads	84%

[1]Observation = `Number of offset positions` $\times$ (Offset overhead + Number of FP settings $\times$ `NDIT` $\times$ (`DIT` + readout overhead + FPI setup + time between frames without offsets))

Table 31: Overheads – Example 10 – A bright source with SDI.

Template parameters	
Acquisition Template	`NACO_img_acq_SDIMoveToPixel`
Observation Template	`NACO_sdi_obs_GenericOffset`
`DIT`	10 seconds
`NDIT`	6
`Number of offset positions`	5
`NEXPO per offset position`	1
`Readout mode`	`Double_RdRstRd`
`List of Position Angle Offsets`	0 33
`Return to the Original Rotator Position?  (T/F)`	F
Execution time	
Preset	3 minutes
Guide Star Acquisition	0.75 minutes
Initial Setup	2 minutes
AO acquisition	5 minutes
SDI acquisition	1 minutes
Sub-total	11.75 minutes
Observation at 0 degrees[1] = 5*(27 + 6 * 10 + 0.7)	7.3 minutes
Rotator offset	1 minute
Observation at 33 degrees = 5*(27 + 6 * 10 + 0.7)	7.3 minutes
Total	27.3 minutes
Overheads	173%

[1]Observation = `Number of offset positions` $\times$ (Offset overhead + `NDIT` $\times$ `DIT` + readout overhead)

6 NAOS-CONICA templates

6.1 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 32 provides a short summary of the templates offered for period 81. 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.

6.2 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 (including observations with the Fabry Perot) must use the `NACO_img_acq_MoveToPixel` template for acquisition. The `NACO_img_acq_Preset` template has been removed. See Sec. 5.7.

- All polarimetric observations with the wire grids must use the `NACO_img_acq_MoveToPixel` template for acquisition. See Sec. 5.7.

- All polarimetric observations with the Wollaston prisms 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 and SDI+ must use `NACO_img_acq_SDIMoveToPixel` for acquisition.

- All observations with the SDI +4 must use `NACO_img_acq_SDIMoveToMask` 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. 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.

Table 32: NACO templates: cookbook

Action	Template(s) to use
Acquisition	
Turn the field (= telescope rotator)	`NACO_all_obs_Rotate`
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 center object(s) in the slit (spectroscopy)	`NACO_img_acq_MoveToSlit`
Preset telescope and center object behind the mask (coronagraphy)	`NACO_img_acq_MoveToMask`
Preset telescope and center object behind the mask in SDI+4	`NACO_img_acq_SDIMoveToMask`
General to all observing templates	
Make a rotator offset	`NACO_all_obs_Rotate`
Imaging or Wire Grid Polarimetry	
Imaging of uncrowded 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 SDI	`NACO_sdi_obs_GenericOffset`
Spectroscopy	
Spectroscopy of point–like or moderately extended objects	`NACO_spec_obs_AutoNodOnSlit`
Spectroscopy of extended objects (i.e. wider than ∼ 10 arc seconds) or complex sequences of slit positions	`NACO_spec_obs_GenericOffset`
Polarimetry	
Imaging Polarimetry	`NACO_pol_obs_GenericOffset`
Polarimetry with Half-Wave Plate	`NACO_pol_obs_Retarder`
Coronagraphy	
Coronagraphy without chopping	`NACO_coro_obs_Stare`
	`NACO_coro_obs_Astro`
SDI+4	
4QPM Coronagraphy with SDI+	`NACO_sdi4_obs_Stare`
Standard Stars	
Standard Star (Imaging)	`NACO_img_cal_StandardStar`
Standard Star (Fabry Perot Imaging)	`NACO_fpi_cal_StandardStar`
Standard Star (Coronagraphy)	`NACO_coro_cal_StandardStar`
Standard Star (Spectroscopy)	`NACO_spec_cal_StandardStar`
Standard Star (Polarimetry)	`NACO_pol_cal_StandardStar`
Night Time Calibrations	
Night time Coronagraphic and SDI+4 Flats	`NACO_coro_cal_NightCalib`
Night time Spec. Flats and Arcs	`NACO_spec_cal_NightCalib`

- With the exception of standards, the minimum amount of time between exposures is 30 seconds.

- Ensure that the correct filters are used when acquiring bright targets for spectroscopy. See section 5.15.

- 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 be in the slit at the same time. Additionally the co-ordinates 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. See Sec. B.8 for more details.

6.2.1   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.

6.3   Offset conventions and definitions
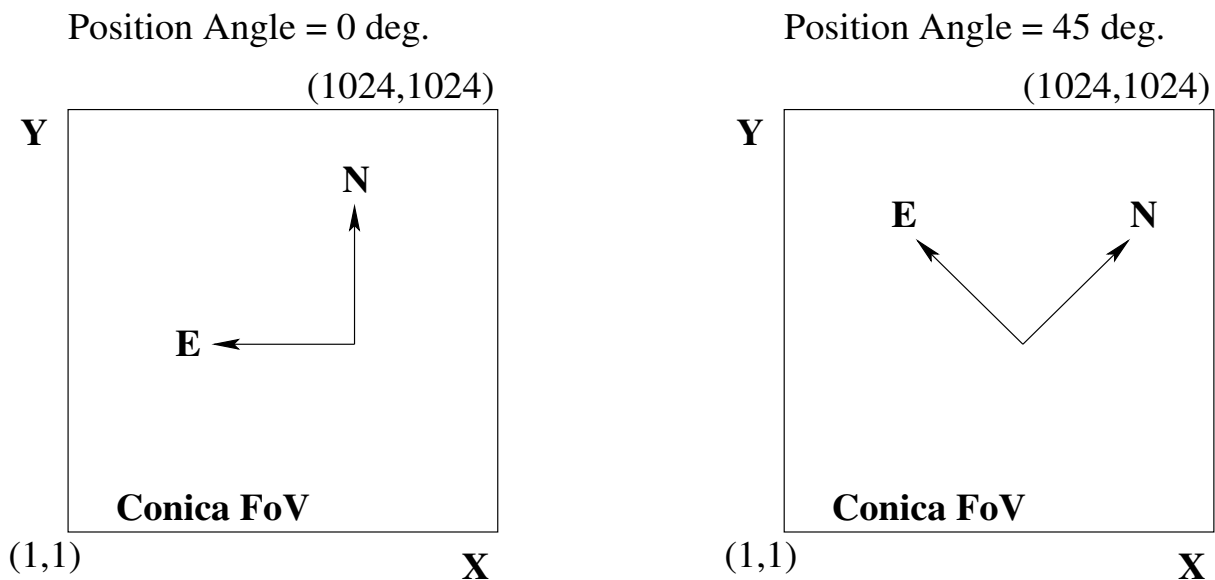
Figure 17: Orientation for imaging, polarimetry and coronagraphy. (Left): Field orientation on detector at 0° rotation angle on sky, (Right): Field orientation at $+45^o$ rotation angle on sky.

Position Angle = 0 deg.   Position Angle = 45 deg.
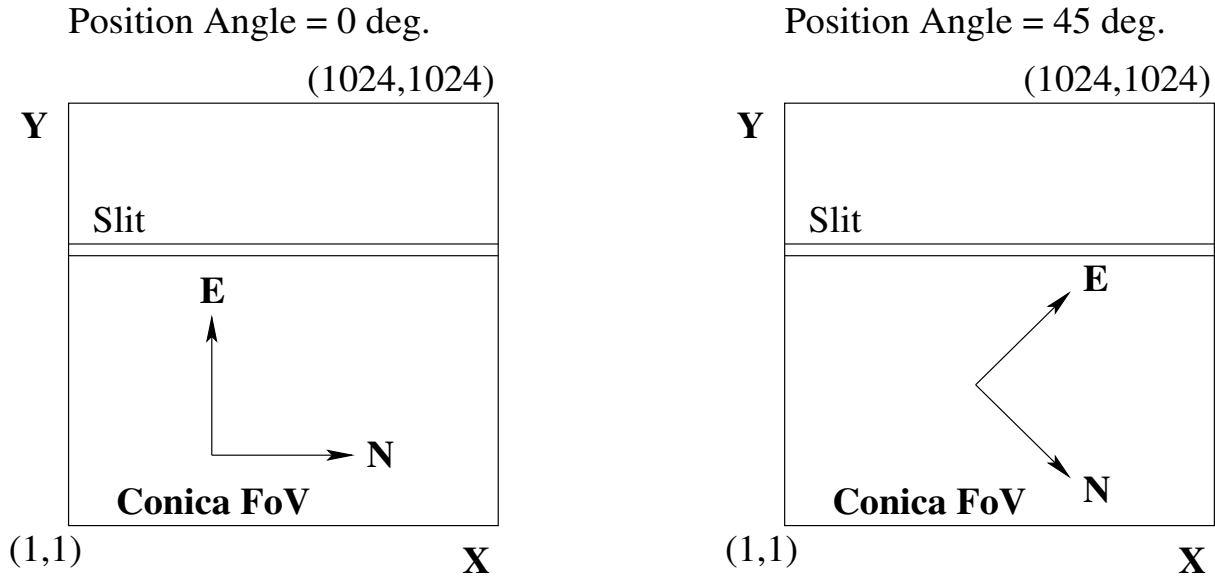
Figure 18: Orientation for spectroscopic observations . (Left): Field orientation on detector at 0° rotation angle on sky, (Right): Field orientation at $+45^o$ rotation angle on sky.

- 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.

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

Reminder: the minimum time between exposures is 30 seconds.

6.4 Acquisition Templates

6.4.1 Introduction

Telescope presets can only be done via acquisition templates and all observing blocks must start with one. There are six acquisition templates: two for imaging and wire grid polarimetry, and one each for SDI imaging, spectroscopy, coronagraphy and polarimetry with the Wollaston. They are listed in Table 32.

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`, 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.

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 `HighSensitivity`. The minimum DITs for these modes are listed in Tab. 15.

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. Filter curves are plotted in Fig. 29.

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.

6.4.2 `NACO_img_acq_MoveToPixel`

This template does a telescope preset and is followed by interactive centering of the object. It should be used when precise positioning of the object is required. It must be followed by an imaging template.

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

In visitor mode, the interactive part of the template will be executed by the instrument operator under the supervision of the visiting astronomer. In service mode, it is mandatory that users users provide detailed information for the field centering on their Finding Charts and/or in their README file.

Table 33 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 33: Parameters of `NACO_img_acq_MoveToPixel`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
NDIT	NODEFAULT	Number of DITs
PSF reference? (T/F)	F	PSF reference (T/F)?
RA offset (arcsec)	5	RA offset for fixed pattern (arcsec)
DEC offset (arcsec)	5	DEC offset for fixed pattern (arcsec)
Position Angle on Sky	0	Position angle in degrees
Add Velocity Alpha [1]	0	Additional tracking vel. in RA
Add Velocity Delta [1]	0	Additional tracking vel. in DEC
Filter	NODEFAULT	Filter Name
Neutral density filter	Full	Neutral density filter
Camera	NODEFAULT	Camera Name
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
NAOS parameter file	NODEFAULT	NAOS parameter file

[1] In arcsec/sec

6.4.3   `NACO_img_acq_SDIMoveToPixel`

This template is very similar to the `NACO_img_acq_MoveToPixel` template with the exception that the camera and the filter are not parameters of the template. It should only be used to aquire targets for SDI. The template does a telescope preset and is followed by interactive centering of the object. It must be followed by either an imaging template or an SDI template.

In visitor mode, the interactive part of the template will be executed by the instrument operator under the supervision of the visiting astronomer. In service mode, it is mandatory that users provide detailed information for the field centering on their Finding Charts and/or in their README file.

Table 34 describes the parameters of this template.

Table 34: Parameters of `NACO_img_acq_SDIMoveToPixel`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
NDIT	NODEFAULT	Number of DITs
PSF reference? (T/F)	F	PSF reference (T/F)?
RA offset (arcsec)	5	RA offset for fixed pattern (arcsec)
DEC offset (arcsec)	5	DEC offset for fixed pattern (arcsec)
Position Angle on Sky	0	Position angle in degrees
Add Velocity Alpha [1]	0	Additional tracking vel. in RA
Add Velocity Delta [1]	0	Additional tracking vel. in DEC
Neutral density filter	Full	Neutral density filter
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
Camera	NMODEFAULR	SDI or SDI+ camera
NAOS parameter file	NODEFAULT	NAOS parameter file

[1] In arcsec/sec

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. If three images are recorded, then the first two are images of the reference and they are used by the operator to help classify the OB.

6.4.4 `NACO_img_acq_MoveToSlit`

This template does a telescope preset and is followed by interactive centering of the object in the slit. It is very similar to the `NACO_img_acq_MoveToPixel` 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 centering 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 35 describes the parameters of this template.

Table 35: Parameters of `NACO_img_acq_MoveToSlit`

P2PP label	Default	Description
`DIT`	NODEFAULT	Detector Integration Time (secs)
`NDIT`	NODEFAULT	Number of `DIT`s
`PSF reference?  (T/F)`	F	PSF reference (T/F)?
`Alpha offset from Ref Star`	0	Offset from Ref. Star (arcsec)
`Delta offset from Ref Star`	0	Offset from Ref. Star (arcsec)
`RA offset (arcsec)`	5	RA offset for fixed pattern (arcsec)
`DEC offset (arcsec)`	5	DEC offset for fixed pattern (arcsec)
`Position Angle on Sky`	0	Position angle in degrees
`Add Velocity Alpha` [1]	0	Additional tracking vel. in RA
`Add Velocity Delta` [1]	0	Additional tracking vel. in DEC
`Filter`	NODEFAULT	Filter Name
`Neutral density filter`	Full	Neutral density filter
`Camera`	NODEFAULT	Camera Name
`Slit`	NODEFAULT	Slit Name
`Type of AO Observation (LGS/NGS)`	NODEFAULT	LGS or NGS observation type
`NAOS parameter file`	NODEFAULT	NAOS parameter file

[1] In arcsec/sec

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 centered 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 86mas 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 help 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 centered. If reference offsets are used, an additional image (either the 3rd or the 5th image recorded to disk) is taken after the reference offset.

6.4.5 `NACO_img_acq_MoveToMask`

This template does a telescope preset and is followed by interactive centering 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 centering 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 centering with the 4QPM mask, we recommend that users use the S13 objective.

Table 36 describes the parameters of this template.

Table 36: Parameters of `NACO_img_acq_MoveToMask`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
NDIT	NODEFAULT	Number of DITs
PSF reference? (T/F)	F	PSF reference (T/F)?
RA offset (arcsec)	5	RA offset for fixed pattern (arcsec)
DEC offset (arcsec)	5	DEC offset for fixed pattern (arcsec)
Position Angle on Sky	0	Position angle in degrees
Add Velocity Alpha [1]	0	Additional tracking vel. in RA
Add Velocity Delta [1]	0	Additional tracking vel. in DEC
Filter	NODEFAULT	Filter Name
Mask Position	NODEFAULT	Coronagraphic mask
Neutral density filter	Full	Neutral density filter
Camera	NODEFAULT	Camera Name
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
NAOS parameter file	NODEFAULT	NAOS parameter file

[1] In arcsec/sec

This template records either two or four images. If only two images are recorded, then the first image is an image of the approximately centered target without the mask and the second image is an image of the target accurately centered 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 help in classifying the OB.

6.4.6 `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. Exception to this rule, is the use of the neutral density filter (ND_Short) for the acquisition of very bright targets.

The star is first acquired in a suitable position 2" away from the center of the 4QPM and an image is recorded to serve as out-of-mask PSF for photometric reference. Then the following steps are performed:

- rough offset to position the star behind the mask

- removal of the ND_Short filter

- adapt DIT if needed

- fine centring

- record the final acquisition image

Table 37 describes the parameters of this template.

Table 37: Parameters of `NACO_img_acq_SDIMoveToMask`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
NDIT	NODEFAULT	Number of DITs
PSF reference? (T/F)	F	PSF reference (T/F)?
RA offset (arcsec)	5	RA offset for fixed pattern (arcsec)
DEC offset (arcsec)	5	DEC offset for fixed pattern (arcsec)
Position Angle on Sky	0	Position angle in degrees
Add Velocity Alpha [1]	0	Additional tracking vel. in RA
Add Velocity Delta [1]	0	Additional tracking vel. in DEC
Filter	NODEFAULT	Filter Name (H or empty)
Neutral density filter	Full_Uszd	Full_Uszd mask or Neutral density filter
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
NAOS parameter file	NODEFAULT	NAOS parameter file

[1] In arcsec/sec

6.4.7 `NACO_img_acq_Polarimetry`

This template does a telescope preset and is followed by interactive centering 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 centering 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 templates allow one to set the angle before each template starts.

Table 38 describes the parameters of this template.

Table 38: Parameters of `NACO_img_acq_Polarimetry`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
NDIT	NODEFAULT	Number of DITs
PSF reference? (T/F)	F	PSF reference (T/F)?
RA offset (arcsec)	5	RA offset for fixed pattern (arcsec)
DEC offset (arcsec)	5	DEC offset for fixed pattern (arcsec)
Position Angle on Sky	0	Position angle in degrees
Add Velocity Alpha [1]	0	Additional tracking vel. in RA
Add Velocity Delta [1]	0	Additional tracking vel. in DEC
Filter	NODEFAULT	Filter Name
Neutral density filter	Full	Neutral density filter
Camera	NODEFAULT	Camera Name
Which Polarimetric Mask	Wollaston_00	Polarimetric mask
Type of AO Observation (LGS/NGS)	NODEFAULT	LGS or NGS observation type
NAOS parameter file	NODEFAULT	NAOS parameter file

[1] In arcsec/sec

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 help classify the OB.

6.5   Imaging and Wire Grid Polarimetry

6.5.1   Introduction

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 polarimetry with the wire grids, set the `Wire grid` parameter to one of the four wire grids (See Tab. 13). For imaging observations, set this parameter to empty. Note that wire grid polarimetry observations can also be performed with the half-wave plate with the special template `NACO_pol_obs_Retarder`(see 6.8.3).

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.

6.5.2   `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.

Table 39 describes the parameters of this template.

Table 39: Parameters of `NACO_img_obs_AutoJitter`

P2PP label	Default	Description
`Observation Category`	SCIENCE	Observation Category
`DIT`	NODEFAULT	Detector Integration Time (secs)
`NDIT`	NODEFAULT	Number of DITs
`Readout mode`	`Double_RdRstRd`	Readout mode
`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
`Wire grid`	empty	Wire grid (use empty for imaging)
`Camera`	NODEFAULT	Camera Name

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.

The value of the "`Jitter Box Width`" parameter corresponds to the **full width** of the box in which the
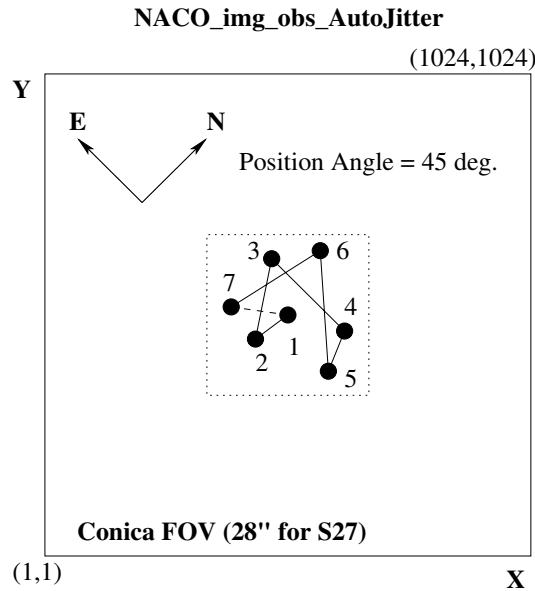
NACO_img_obs_AutoJitter

Figure 19: An illustration of how the NACO img obs AutoJitter template works with:

```
Jitter Box Width = 10
NEXPO per offset position  = 1
Number of offset positions = 7
Return to Origin ?  (T/F) = T
Camera = S27
```

The last dashed line (joining 7 to 1) is the offset at the end of the template since the Return to Origin ? (T/F) was set to T. The dotted box defines the Jitter Box Width.

---

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

6.5.3 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 40 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

Table 40: Parameters of `NACO_img_obs_GenericOffset`

P2PP label	Default	Description
`Observation Category`	SCIENCE	Observation Category
`DIT`	NODEFAULT	Detector Integration Time (secs)
`Readout mode`	`Double_RdRstRd`	Readout mode
`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 with AO, S is without
`Offset Coordinates`	NODEFAULT	SKY or DETECTOR
`List of offsets in RA or X`	NODEFAULT	Offset in arcseconds
`List of offsets in DEC or Y`	NODEFAULT	Offset in arcseconds
`Return to Origin ?  (T/F)`	T	Return to the origin at the end
`Rotate Pupil ?`	F	Rotate the pupil in sky frames
`Filter`	NODEFAULT	Filter Name
`Neutral density filter`	Full	Neutral density filter
`Wire grid`	empty	Wire grid (use empty for imaging)
`Camera`	NODEFAULT	Camera Name

"`Observation Type (O or S)`." O stands for `Object` and assigns the `DPR TYPE` header keyword to OB-JECT. 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.

The template provides the possibility of rotating the instrument between object and sky frames so that pupil ghosts can be minimised (all object frames have the same position angle on sky). The technique has proved to be efficient with SOFI and ISAAC. For NAOS-CONICA, it is not required for observations with the SW filters, but it may be needed for the LW filters. For mosaics, it should be set to False.

At the end of the template, the telescope is returned to the original position if the parameter "`Return to Origin ?  (T/F)`" is set to true (T). If not, the telescope is not moved at the end of the template.

Figs. 20 and 21 illustrate how this template can be used.

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

$$\mathtt{DIT} \times \sum_{1}^{\text{Number of offset positions}} \mathtt{NDIT}\,(i) \times \mathtt{NEXPO\ per\ offset\ position}$$

6.5.4 `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
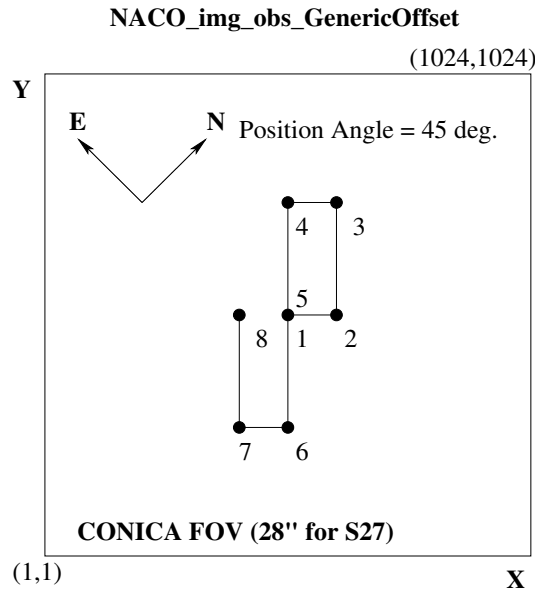
NACO_img_obs_GenericOffset

Figure 20: 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, and the telescope will not return to the origin after the eighth exposure. The parameter settings for this example were:

```
NEXPO per offset position  = 1
Number of offset positions = 8
Return to Origin ?   (T/F) = F
Camera = S27
Observation Type (O or S) = O
Offset Coordinates = DETECTOR
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
```

---

parameters SEQ SKYOFFSET DEC and SEQ SKYOFFSET RA) from the original telescope position and within a box whose dimensions are set by the parameter "Jitter Box Width" (in arcsec).

This template is similar to the the NACO_img_obs_AutoJitterOffset template, but instead of a randomly positioned sky frame, the user specifies the exact location of the sky frame through the SEQ SKYOFFSET DEC and SEQ SKYOFFSET RA keywords.

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

Table 41 describes the parameters of this template.

By default, 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 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.
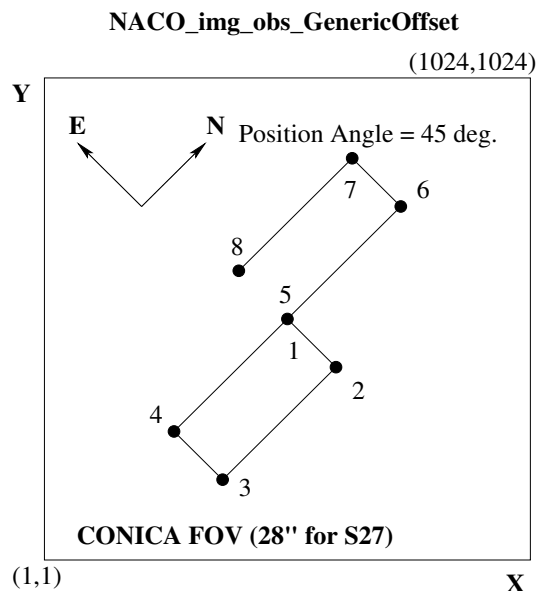
NACO_img_obs_GenericOffset

Figure 21: 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 will not return to the origin after the eighth exposure. The parameter settings for this example were:

```
NEXPO per offset position  = 1
Number of offset positions = 8
Return to Origin ?   (T/F) = F
Camera = S27
Observation Type (O or S) = O
Offset Coordinates = SKY
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
```

The template provides the possibility of rotating the instrument between object and sky frames so that pupil ghosts can be minimised (all object frames have the same position angle on sky). The technique has proved to be efficient with SOFI and ISAAC. For NAOS-CONICA, it is not required for observations with the SW filters, but it may be needed for the LW filters.

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 × 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.

Fig. 22 illustrates how this template can be used.
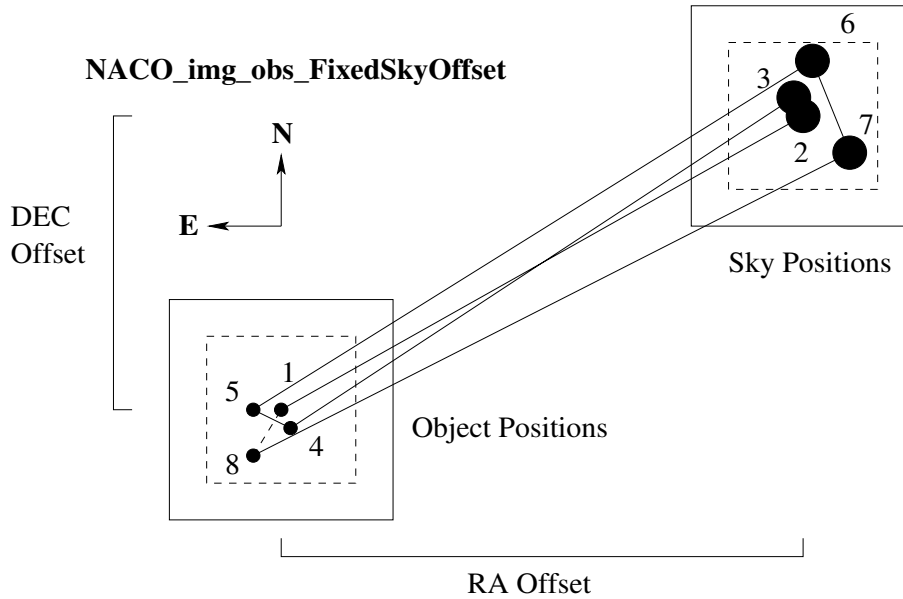
Figure 22: An illustration of how the NACO_img_obs_FixedSkyOffset template works with:

```
Jitter Box Width = 9
Number of AB or BA cycles = 4
Sky offset in Dec. = 15
Sky offset in RA. = -35
Return to Origin ?  (T/F) = T
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 of the telescope since Return to Origin ? (T/F) is set to T. The dashed box is defined by the Jitter Box Width.

Table 41: Parameters of `NACO_img_obs_FixedSkyOffset`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
Readout mode	Double_RdRstRd	Readout mode
Jitter Box Width	NODEFAULT	Jitter Box Width
Number of AB or BA cycles	NODEFAULT	One cycle is an object-sky pair
NDIT for the OBJECT positions	NODEFAULT	Number of DITs at the object position
NDIT for the SKY positions	NODEFAULT	Number of DITs at the sky position
NEXPO per offset position	1	Number of exposures per offset position
Return to Origin ? (T/F)	T	Return to origin at the end of the template
Rotate Pupil ?	F	Rotate the pupil in sky frames
Sky offset in Dec.	NODEFAULT	Declination offset in arcseconds
Sky offset in RA.	NODEFAULT	RA offset in arcseconds
Filter	NODEFAULT	Filter Name
Neutral density filter	Full	Neutral density filter
Wire grid	empty	Wire grid (use empty for imaging)
Camera	NODEFAULT	Camera Name

6.5.5 `NACO_img_cal_StandardStar`

This template is used for imaging standards and 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 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 42 describes the parameters of this template.

Table 42: Parameters of `NACO_img_cal_StandardStar`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
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
List of offsets in X	NODEFAULT	Offset in arcseconds
List of offsets in Y	NODEFAULT	Offset in arcseconds
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
Wire grid	empty	Wire grid (use empty for imaging)
Camera	NODEFAULT	Camera Name

6.6   SDI

6.6.1   Introduction

The simultaneous differential imager (SDI and SDI+) uses special templates to acquire (see Sec.6.4.3) and observe targets.

6.6.2   `NACO_sdi_obs_GenericOffset`

This template is used exclusively with the SDI and SDI+ modes. 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 have 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 43 describes the parameters of this template.

Table 43: Parameters of `NACO_sdi_obs_GenericOffset`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
Readout mode	Double_RdRstRd	Readout mode
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 with AO, S is without
List of offsets in X	NODEFAULT	Offset in arcseconds
List of offsets in Y	NODEFAULT	Offset in arcseconds
Return to the Original		Return to original rotator
Rotator Position ? (T/F)	F	position at end of the template
List of Position Angle Offsets	NODEFAULT	List of rotator offsets in degrees
Neutral density filter	Full	Neutral density filter
Camera	NODEFAULT	SDI or SDI+ camera

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:

`the 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 is 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 positions` × `the number of rotator positions`

6.7   Spectroscopic Templates

6.7.1   Introduction

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 arc seconds.

6.7.2   `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 44 describes the parameters of this template.

Table 44: Parameters of `NACO_spec_obs_AutoNodOnSlit`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
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 an object-sky pair
NEXPO per offset position	1	Number of exposures
Nod throw	NODEFAULT	Nod Throw in arc seconds
Return to Origin ? (T/F)	T	Return to origin
Slit	NODEFAULT	Name of the slit
Spectroscopic Mode	NODEFAULT	Spectroscopic Mode

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 $+\frac{Nodthrow}{2}$ arcsec. The second exposure (B) is therefore $-\frac{Nodthrow}{2}$ arcsec 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:

$$A(B+\epsilon_1)(B+\epsilon_1)(A+\epsilon_2)(A+\epsilon_2)(B+\epsilon_3)(B+\epsilon_3)(A+\epsilon_4)\ (A+\epsilon_4)(B+\epsilon_5)(B+\epsilon_5)(A+\epsilon_6)$$

where ϵ_n are random offsets. In order to avoid the possibility of overlapping spectra, ϵ_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 arcsec). Offsets are randomly distributed between $-\frac{JitterBoxWidth}{2}$ and $+\frac{JitterBoxWidth}{2}$. **It is strongly recom-**

mended 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.
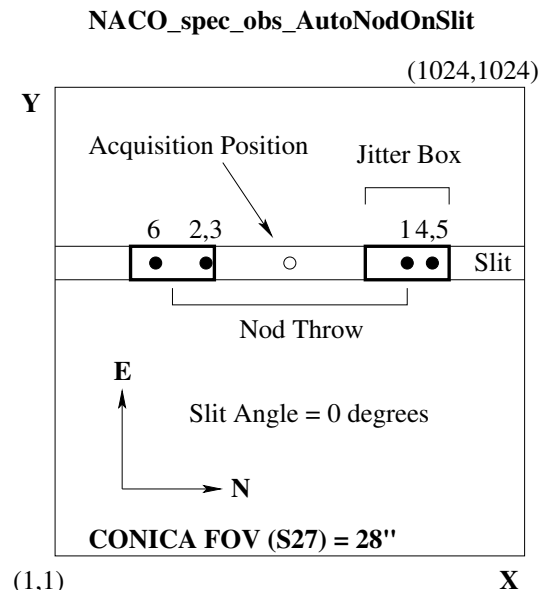

Figure 23: An illustration of how the `NACO_spec_obs_AutoNodOnSlit` template works with:

```
Jitter Box Width = 5
Return to Origin ?  (T/F) = 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 arcseconds between each OB. This is for the following reason: the acquisition is always done at the same position on the array (i.e. center 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 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`

6.7.3 `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 45 describes the parameters of this template.

Table 45: Parameters of `NACO_spec_obs_GenericOffset`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
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 with AO, S is without
Offset Coordinates	NODEFAULT	SKY or DETECTOR
List of offsets in RA or X	NODEFAULT	Offset in arcseconds
List of offsets in DEC or Y	NODEFAULT	Offset in arcseconds
Return to Origin ? (T/F)	T	Return to origin at the end of the template
Slit	NODEFAULT	Name of the slit.
Spectroscopic Mode	NODEFAULT	Spectroscopic Mode

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 OB-JECT. 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 centered 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.
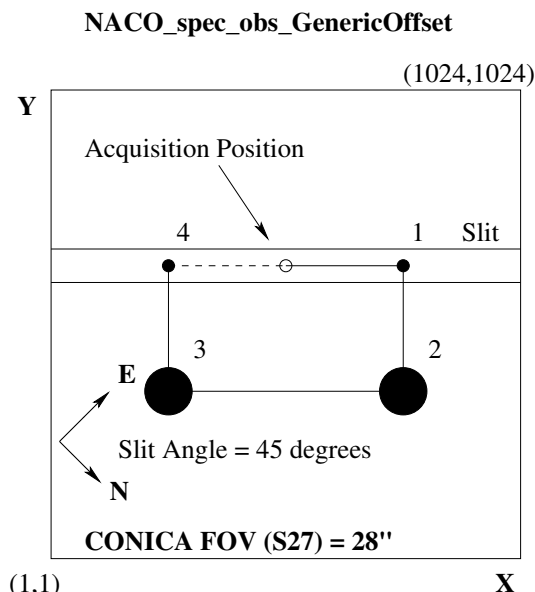
NACO_spec_obs_GenericOffset

Figure 24: 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 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
```

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:

$DIT \times NDIT \times$ `Number of offset positions` $\times$ `NEXPO per offset position`

6.7.4   `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 the description of the `NACO_spec_obs_AutoNodOnSlit` template for the description of the parameters (see section 6.7.2).

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 FITS headers of the images are set to different values allowing pipeline processing and archiving.

6.7.5   `NACO_spec_cal_NightCalib`

This template is used for taking night time 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 flatfield lamp on and one exposure with the flatfield lamp off. If n is set to zero, the default, no lamp flats are taken.

Table 46 describes the parameters of this template.

Table 46: Parameters of `NACO_spec_cal_NightCalib`

P2PP label	Default	Description
`Night Arc?  (T/F)`	F	Night time arc
`Number of Night Flats`	0	Night time flat field

6.8   Polarimetric Templates

6.8.1   Introduction

These templates are for polarimetric observations with the Wollaston prism. For polarimetric observations with the wire grids, please refer to Sec. 6.5.

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 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.

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

6.8.2   `NACO_pol_obs_GenericOffset`

This template is used for imaging polarimetry. It can be used with all filters with the exception of J and M'.

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 have 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:

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

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 47 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 is sampled as desired for one angle

Table 47: Parameters of `NACO_pol_obs_GenericOffset`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
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 with AO, S is without
List of offsets in X	NODEFAULT	Offset in arcseconds
List of offsets in Y	NODEFAULT	Offset in arcseconds
Return to the Original		Return to original rotator
Rotator Position ? (T/F)	F	positition at 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
Polarizer/Grism wheel	Wollaston_00	Polarising element
Camera	NODEFAULT	Camera Name

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 arcsec and the transmitting strips have a width of 3.1 arcseconds. An example of how one may choose to image the entire field of view is given in Fig. 25

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

DIT × NDIT × NEXPO per offset position × Number of offset positions × the number of rotator positions

6.8.3 `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 M' and with either a Wollaston prism or a wire grid polarimeter.

This templates works with defined (generic) offsets. It can follow any of the following acquisition template: `NACO_img_acq_MoveToPixel` or `NACO_img_acq_Polarimetry`. The latter must be used if the Wollaston prism will be used.

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`

NACO_pol_obs_GenericOffset

CONICA FOV (S27) = 28"   (1024,1024)   (1024,1024)

Y   Y

1   6   7   1   6   7

2 5 8   ←Opaque strips→   2 5 8

3   4   9   3   4   9

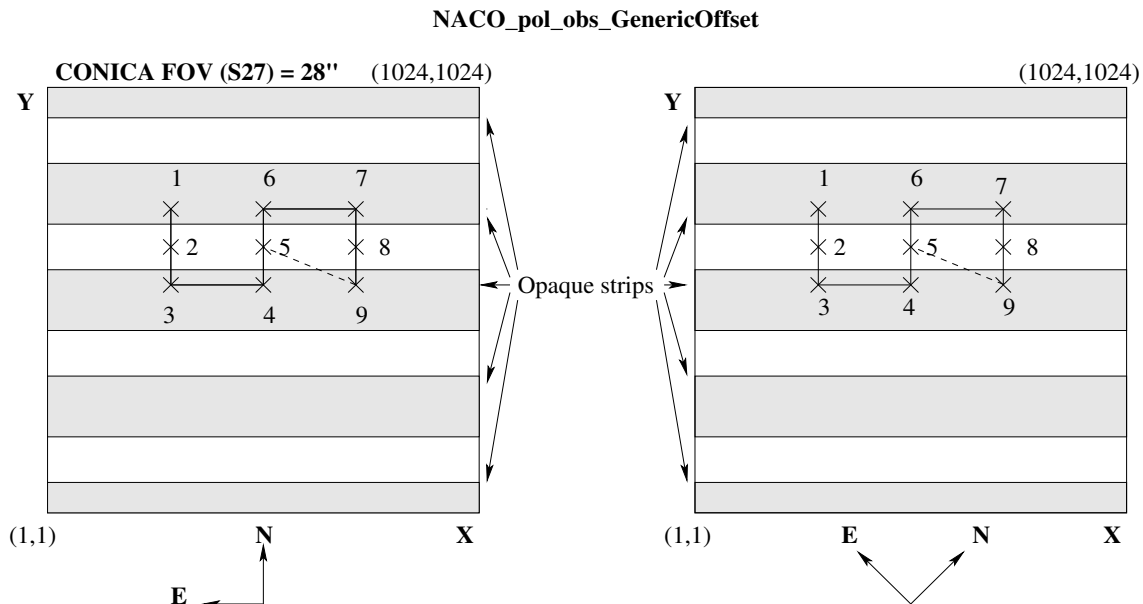(1,1)   N   X   (1,1)   E   N   X

E

Figure 25: 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.

---

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 have 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 position × number of half-wave plate angle × Number of offset positions

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 48 describes the parameters of this template.

Table 48: Parameters of NACO_pol_obs_Retarder

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
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 with AO, S is without
List of offsets in X	NODEFAULT	Offset in arcseconds
List of offsets in Y	NODEFAULT	Offset in arcseconds
List of HWP Angle Offsets	NODEFAULT	List of Half-Wave Plate angle in degrees
Filter	NODEFAULT	Filter Name
Neutral density filter	Full	Neutral density filter
Polarizer/Grism wheel	Wollaston_00	Polarising element
Camera	NODEFAULT	Camera Name

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 position × number of half-wave plate angle × Number of offset positions

The angle of the HWP used is reported in the fits header under INS.RETA2.NAME. Previously this keyword did not exist. The angle at which the HWP was set could 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 fitsheader.

6.8.4 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 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. The user is referred to the description of the NACO_pol_obs_GenericOffset template for the description of the parameters (see Sec. 6.8.2).

6.9 Coronagraphic Templates

6.9.1 Introduction

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

6.9.2 `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`, `NACO_img_obs_AutoJitterOffset`, 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 `SEQ SKYOFFSET DEC` and `SEQ SKYOFFSET 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 49 describes the parameters of this template.

Table 49: Parameters of `NACO_coro_obs_Stare`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
Readout mode	Double_RdRstRd	Readout mode
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 the OBJECT positions	NODEFAULT	Number of DITs at the object position
NDIT for the SKY positions	NODEFAULT	Number of DITs at the 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 offset in Dec.	NODEFAULT	Declination offset in arcseconds
Sky offset in RA.	NODEFAULT	RA offset in arcseconds
Filter	NODEFAULT	Filter Name
Mask Position	NODEFAULT	Coronagraphic mask
Camera	NODEFAULT	Camera Name

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.
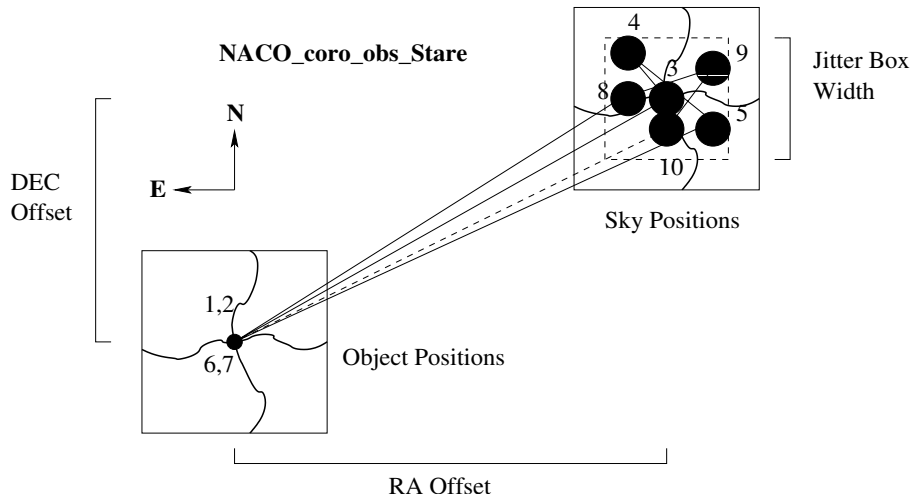
Figure 26: An illustration of how the `NACO_coro_obs_Stare` template works. The dashed line connecting position 10 with 1 is the offset done at the end of the telescope since `Return to Origin ? (T/F)` is set to T. The rather erratic bold lines are wires which hold the coronagraphic mask in place. The 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
Return to Origin ?  (T/F) = T
Camera = S13
```

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 × 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.

6.9.3 `NACO_coro_obs_Astro`

This template is used for Coronagraphic observations.

It runs after a normal coronagraphic acquisition. It takes NEXPO_OBJ 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 principle, 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.

Table 49 describes the parameters of this template.

Table 50: Parameters of `NACO_coro_obs_Astro`

P2PP label	Default	Description
NDIT (img)	NODEFAULT	Number of DITs per image for the imaging
DIT (coro)	NODEFAULT	DIT (secs) for the coronagraphy
DIT (img)	NODEFAULT	DIT (secs) for the imaging (no mask)
Readout mode	Double_RdRstRd	Readout mode
Jitter Box Width	NODEFAULT	Jitter Box Width (Sky only)
NDIT for object positions	NODEFAULT	Num. of DITs at the obj. position under the mask
NDIT for sky positions	NODEFAULT	Num. of DITs at the sky position with the mask
NEXPO Obj only (coro)	NODEFAULT	Num. of exp. with target under the mask
NEXPO per offset position (img)	NODEFAULT	Num. of exposures per imaging position
NOFF sky only (coro)	NODEFAULT	Num. of offsets pos. on sky (with the mask)
NOFF (img)	NODEFAULT	Num. of offsets positions for the imaging
Offset Coordinates	NODEFAULT	SKY or DETECTOR
List of offsets in X	NODEFAULT	Offset in arcseconds
List of offsets in Y	NODEFAULT	Offset in arcseconds
Filter (coro)	NODEFAULT	Filter Name (for the coronagraphy)
Filter (img)	NODEFAULT	Filter Name (for the imaging)
Mask Position	NODEFAULT	Coronagraphic mask
Neutral density filter	Full	Neutral Density Filter
Camera	NODEFAULT	Camera Name

The total **integration** time (excluding overheads) is defined, in seconds, by the sum of the "CORO" time and "IMAGING" time (=time spend 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

6.9.4 `NACO_coro_cal_NightCalib`

This template is used for taking night time flat fields and it should be placed immediately after the coronagraphic or the SDI+4 templates.
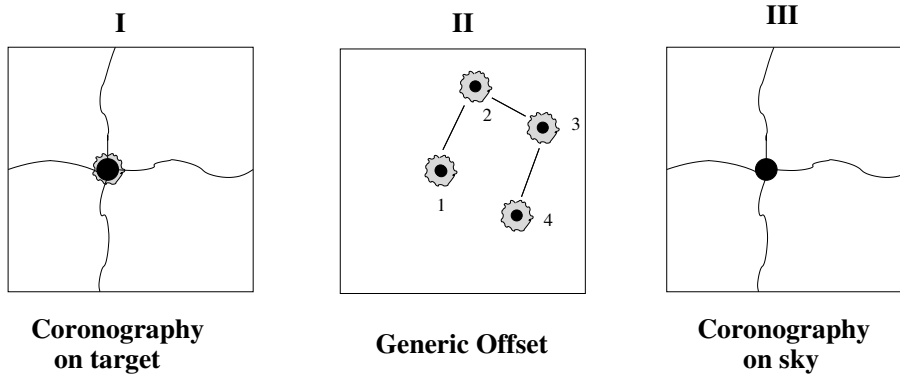
Figure 27: Illustration of how the NACO_coro_obs_Astro template works. The 3 phases of the template are presented. Part I (left): coronagraphy without moving the telescope; part II (middle): simple imaging (the coronagraphic mask is removed). Normally the first offset is zero, to measure the exact position of the target out of the mask. The last offset of the list (NOFF_SKY) bring 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.

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 flatfield lamp on and one exposure with the flatfield 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 51 describes the parameters of this template.

Table 51: Parameters of NACO_coro_cal_NightCalib

P2PP label	Default	Description
Number of Night Flats	1	Night time flat field

6.9.5 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 specifiy the offsets with some care as the purpose of this template is to allow photomotry with the glass plate that holds the coronagraphic mask. Images of the coronagraphic masks are available from the NAOS-CONICA 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 52 describes the parameters of this template.

Table 52: Parameters of `NACO_coro_cal_StandardStar`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
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
List of offsets in X	NODEFAULT	Offset in arcseconds
List of offsets in Y	NODEFAULT	Offset in arcseconds
Return to Origin ? (T/F)	T	Return to origin at the end of the template
Filter	NODEFAULT	Filter Name
Mask Position	C_0.7_sep_10	Coronagraphic mask
Camera	NODEFAULT	Camera Name

6.10   SDI+4 Template

6.10.1   Introduction

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

6.10.2   `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`, `NACO_img_obs_AutoJitterOffset` 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 `SEQ SKYOFFSET DEC` and `SEQ SKYOFFSET 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 53 describes the parameters of this template.

Table 53: Parameters of `NACO_sdi4_obs_Stare`

P2PP label	Default	Description
DIT	NODEFAULT	Detector Integration Time (secs)
Readout mode	Double_RdRstRd	Readout mode
Jitter Box Width	NODEFAULT	Jitter Box Width (Sky only)
Number of AB cycles	NODEFAULT	Num. of AB cycles. E.g. 2 for ABAB
NDIT for the OBJECT positions	NODEFAULT	Num. of DITs at the object position
NDIT for the SKY positions	NODEFAULT	Num. of DITs at the sky position
Number of Exposures (Object Only)	NODEFAULT	Num. of exposures on target
Number of offset positions (Sky only)	NODEFAULT	Num. of exposures on sky
Sky offset in Dec.	NODEFAULT	Declination offset in arcseconds
Sky offset in RA.	NODEFAULT	RA offset in arcseconds
Filter	NODEFAULT	Filter Name (H or empty)

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` × `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 everytime that `Number of Exposures (Object Only)` is greater than 1.

7   acknowledgements

A   Filter Transmission Curves

A.1   CONICA Broad-band imaging and order-sorting filters

The transmission curves at the J, H, Ks, L′, M′ and spectroscopic order-sorting filters are displayed in Figure 28. Electronic versions of the transmission curves of all filters, including the NB and IB filters, are available from the NAOS-CONICA web pages.
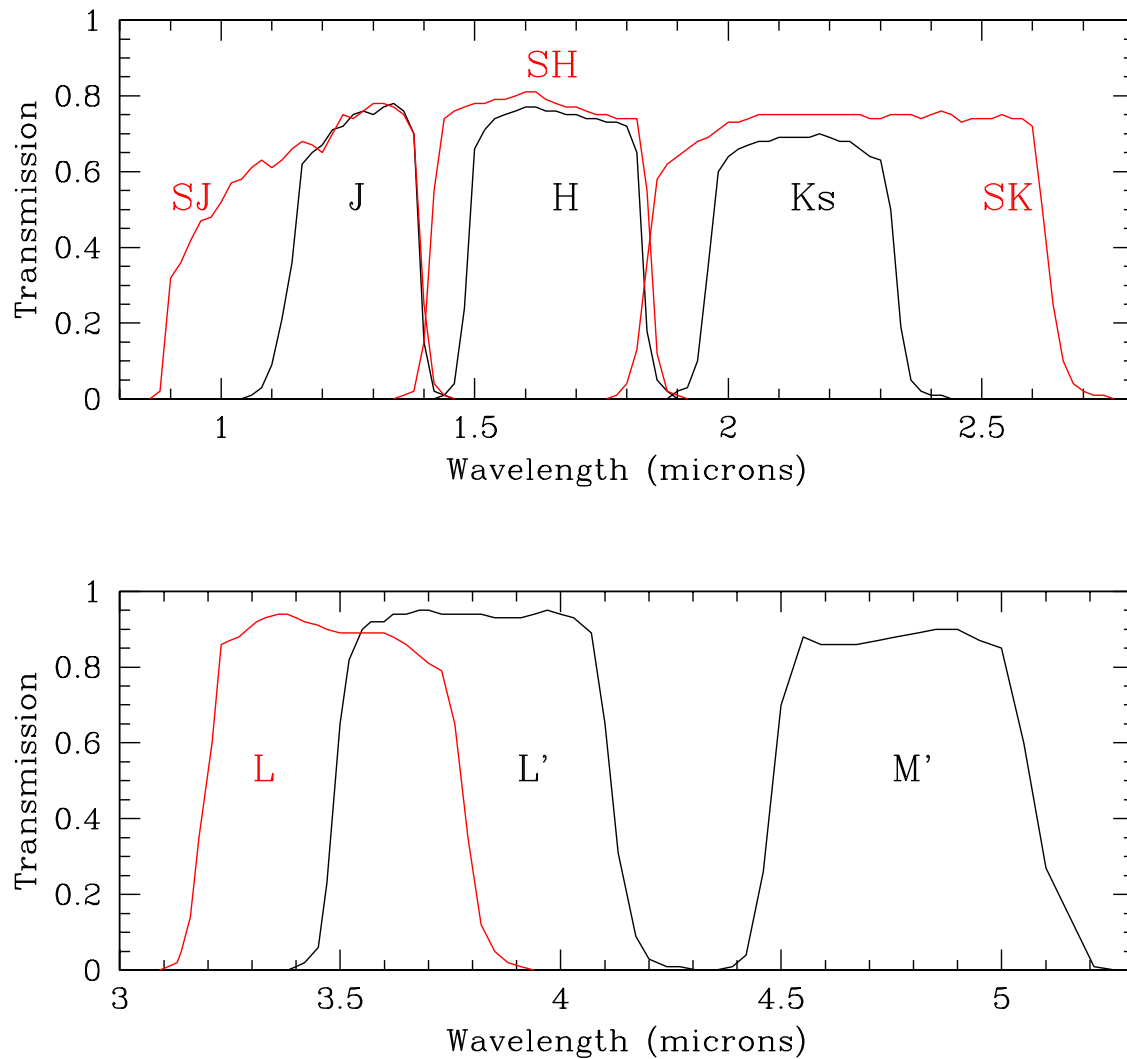

Figure 28: Filter curves for J, H, Ks, L′ and M′, and the order-sorting spectroscopic filters SJ, SK, L. The H and L band filters are also used as order-sorting filters in spectroscopy.

A.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 29.
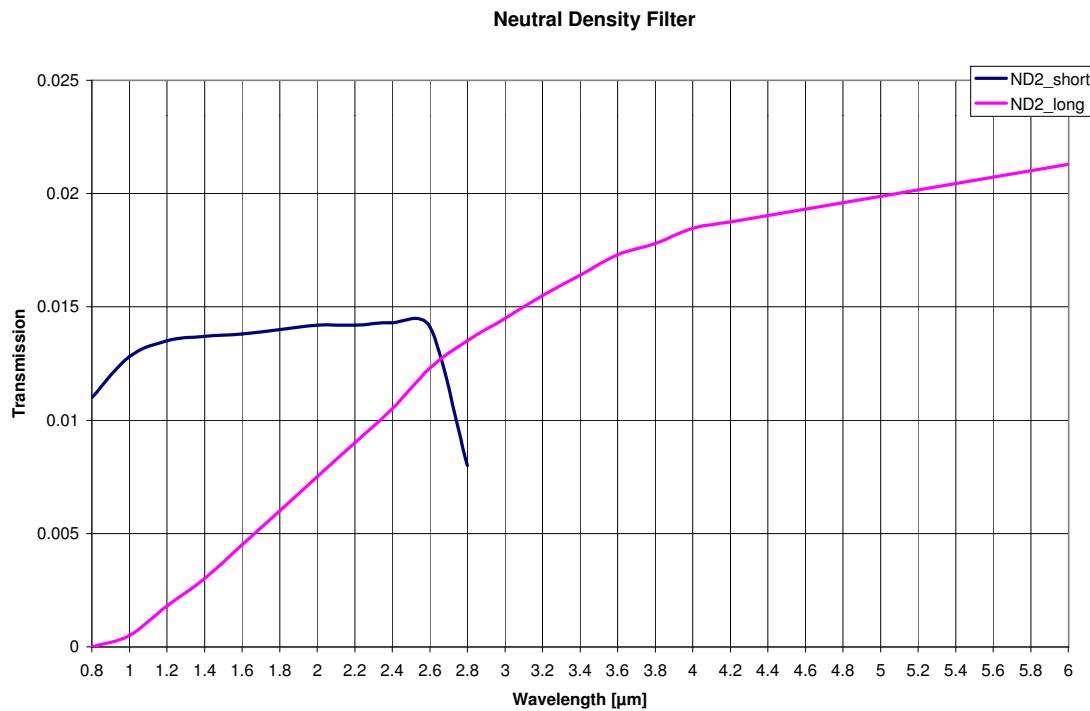
Figure 29: Transmission curves of the neutral density filters in CONICA.

B 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 regular web based interface (`http://www.eso.org/observing/etc/`) or via the HTML file produced by PS. For phase II preparation, the HTML file produced by PS must be used.

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 NAOS-CONICA 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.

B.1 Starting up 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) 1.4.0 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 RedHat 9.

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 (section B.12).

B.2 Graphical User Interface Overview

The GUI that appears after the initialization phase is depicted in Figure 30. 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).

Figure 30: PS Graphical User Interface

- 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.

B.3   Target & 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. Tab. 2 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 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 configuration (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; this is the hardcoded 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.

B.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.

B.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.

B.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 labeled `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 (see section B.5.2).

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.

B.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 arcseconds, and

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

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

B.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:

- `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,L or M), 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).

- `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 31, as defined by Cardelli, Clayton & Mathis (AJ 345, 245 (1989) - section IIIb), and expressed as:

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

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.

B.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 32. 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.
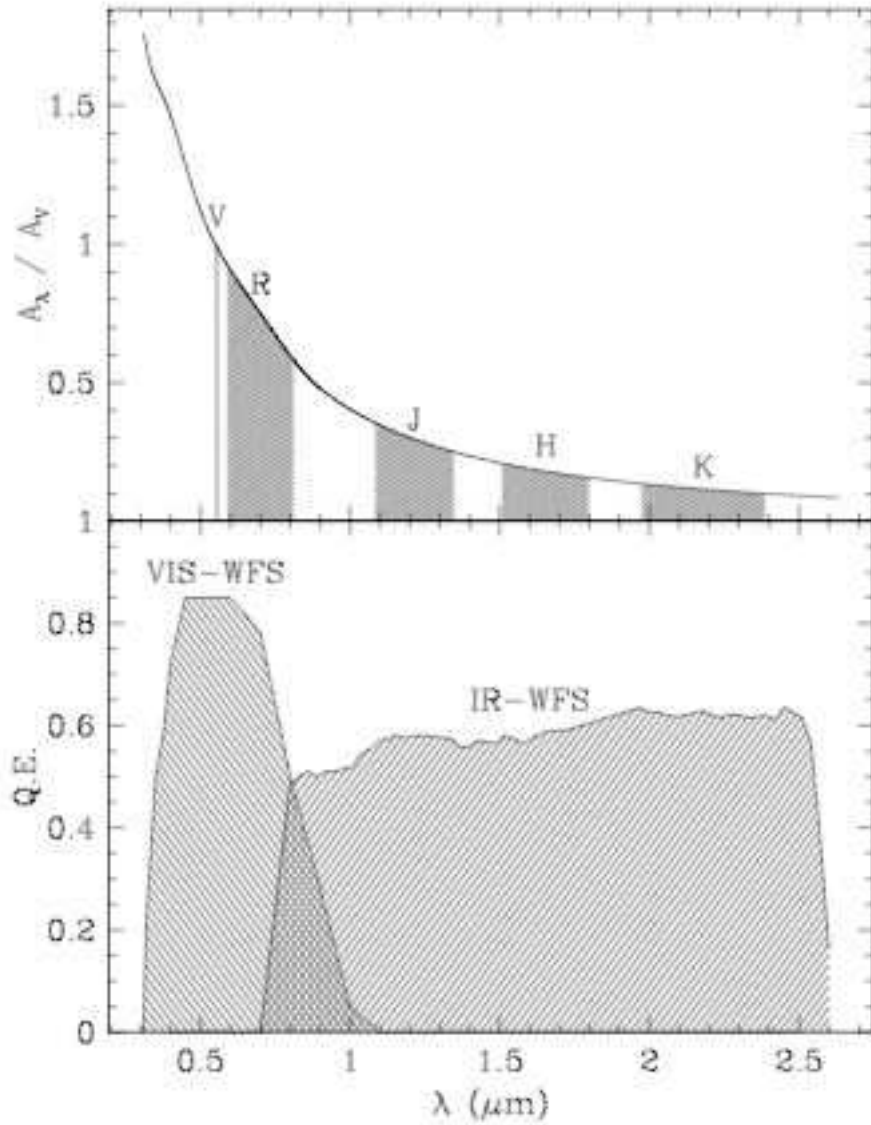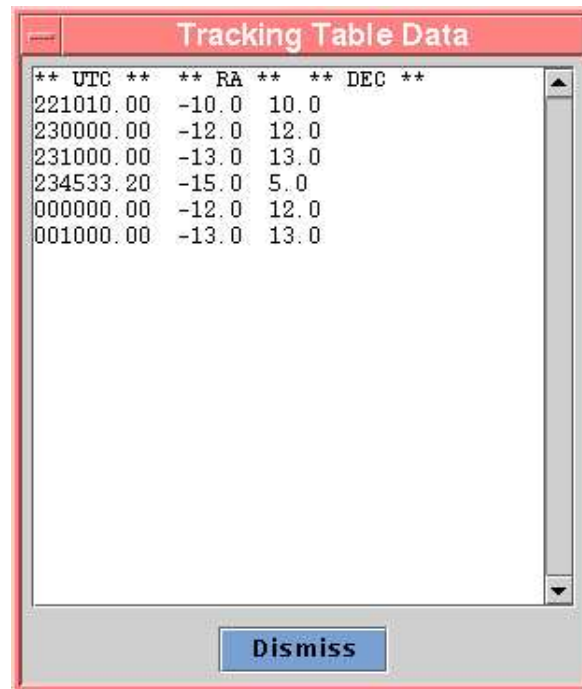
Figure 31: Illustration of the extinction curve used when giving a non zero value to the extinction A_V. The J, H, K and R bands are shown for reference along with the monochromatic wavelength for V. The bottom graph represents the quantum efficiency fo the WFS detectors as a function of wavelength.

B.6   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 33) 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 $2.166\,\mu$m. For the science target (off-axis) the Strehl ratio is given at the observing wavelength only.
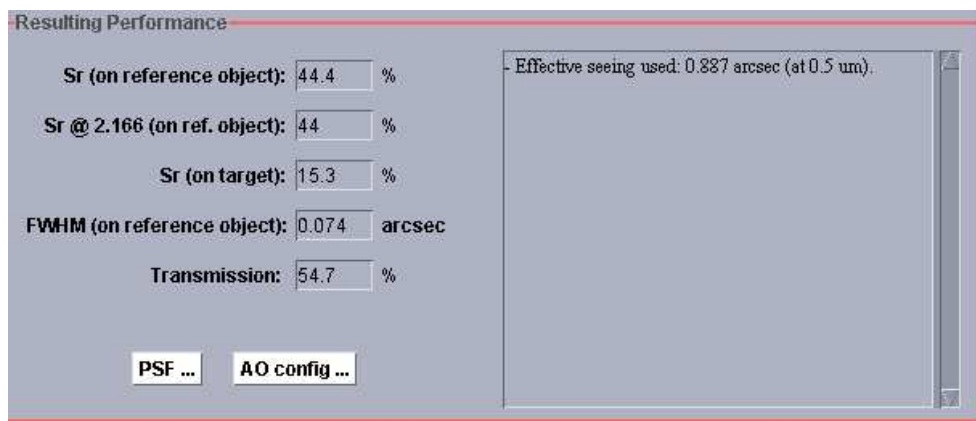
Figure 32: An example of tracking table window (acquisition and observation of moving objects). Offsets in RA and DEC are given in acrseconds

Figure 33: 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 Fig. 34.
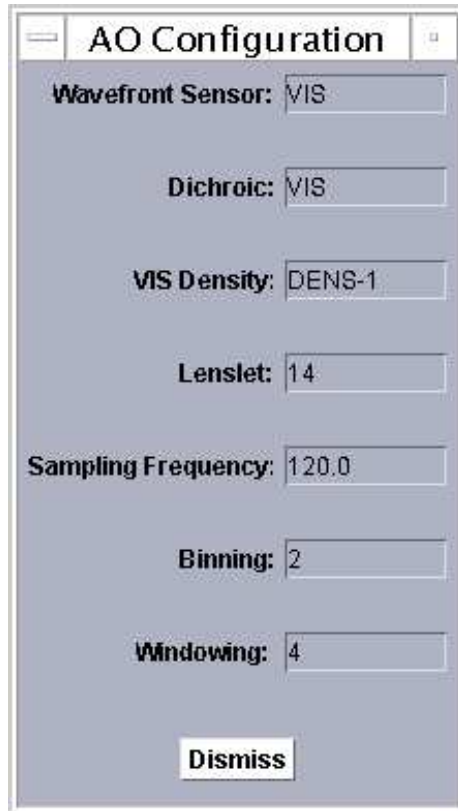

Figure 34: Pop-up window showing an optimal configuration of the AO system.

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 128×128 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 35). 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
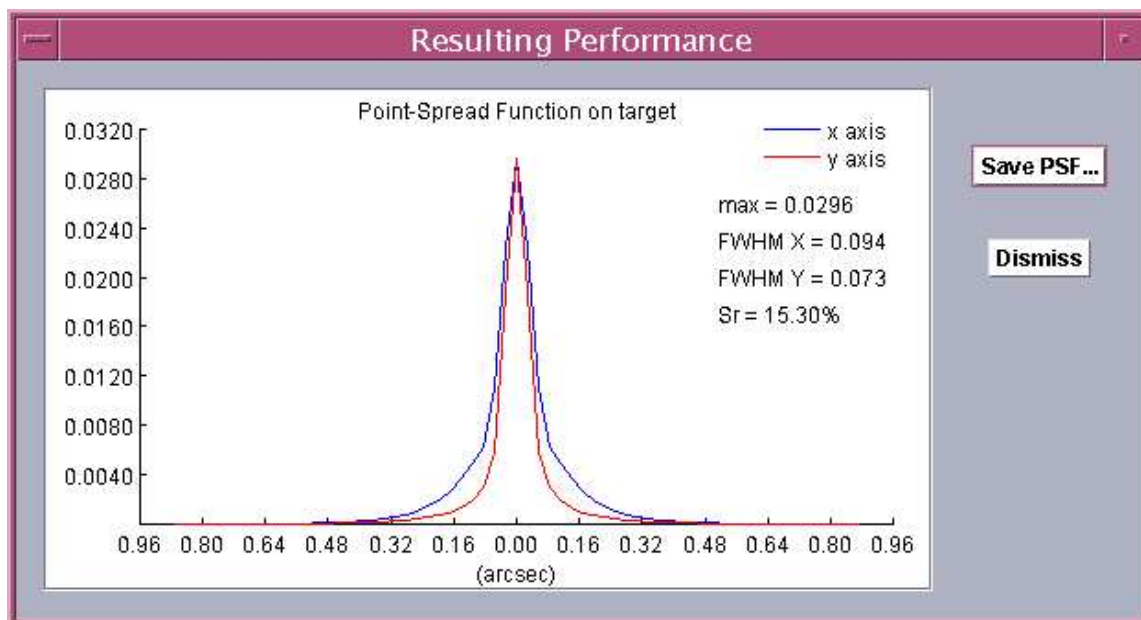
Figure 35: Pop-up window showing the PSF profile. This also gives access to the PSF FITS file. The different width of the PSF in x- and y-direction are due to anisoplanatism. The x-axis is here defined as the axis that is parallel to the line connecting the reference object with the science target.

> 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 (see section 3.3).

- The full width at half-maximum of the PSF is given in arcseconds both in the main panel and in the pop-up window depicted in Figure 35.

- Transmission to CONICA is expressed as a fraction of incoming light, at the observing wavelength.

B.7   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.

B.8   Exporting to P2PP

All NAOS-CONICA acquisition templates (Sec. 6.4) 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.

B.9   Exporting OBs from P2PP

The export facility in P2PP allows one to export observing blocks. For NAOS-CONICA, 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.

B.10   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.

B.11   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.

B.12   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 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/`.

- Set cache folder: 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.

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.