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Adaptive Optics at the VLT: NAOS-CONICA

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Abstract. NAOS-CONICA is the first adaptive optics instrument to be offered to the community at the ESO VLT. This instrument is capable of diffraction limited imaging, spectroscopy, polarimetry and coronography in the 1 to 5 micron wavelength region. In this paper, I will provide a description of the instrument and summarize NAOS-CONICA "end-to-end" operations.

1. Introduction

NAOS-CONICA is the first adaptive optics (AO) instrument to begin operations at the ESO VLT, and the fifth instrument overall since operations began with ISAAC and FORS1 as the first two instruments on Antu[1] in 1999. NAOS-CONICA is located on Yepun, which also hosts FORS2 and came into operations in 2001.

2. NAOS-CONICA

An image of NAOS-CONICA attached to the Nasmyth B focus of Yepun is shown in Figure 1. NAOS-CONICA consists of two instruments: NAOS (Rousset et al. 2002, Lacombe et al. 2002), which is the AO part of NAOS-CONICA (in Figure 1 it can be seen attached directly to the telescope) and CONICA (Lenzen et al. 2002), which is the IR camera and spectrograph that is attached to the back of NAOS.

The process of bringing an instrument into operations on the VLT follows a process of commissioning, where the instrument is integrated, attached to the telescope and tested, and *Paranalization*, where operational procedures are defined, calibration methods are tested, and readiness for science operations is assessed. Commissioning of NAOS-CONICA started in November, 2001; first light occurred on November 25th; Paranalization started in May 2002 and Operations started on September 30th, 2002.

[1]The four 8m telescopes are called Antu (VLT-UT1), Kueyen (VLT-UT2), Melipal (VLT-UT3) and Yepun (VLT-UT4), which, in the Mapuche language, translate to The Sun, The Moon, The Southern Cross and The Evening Star.

Figure 1. NAOS-CONICA on the Nasmyth B focus of Yepun. From left to right, one can identify the Nasmyth B rotator (dark blue), NAOS (light blue), the back-end of NAOS (white), CONICA (red) and the cables that transport coolant, power and signals between NAOS-CONICA and the co-rotator.

2.1. NAOS

NAOS takes the uncorrected beam from the telescope and provides a turbulence compensated F/15 beam and a 2 arc-minutes FOV to CONICA. The wavefront distortions are measured with sensors that use Shack-Hartmann screens and compensated via tip-tilt and deformable mirrors, the latter of which has 185 actuators. NAOS can work with natural reference sources that are either point like or extended and can select them over a 2 arc-minute FOV. Provisions have been made for it to work with a laser guide star.

NAOS can do the wavefront sensing either in visible (0.4–1.0 microns) or IR light (1.0–2.5 microns) and can perform partial correction for reference sources as faint at $V \approx 17$ and $K \approx 12$. Full correction, where the PSF core becomes diffraction limited, occurs with brighter reference sources.

Five dichroics can be used to split different fractions of visible and IR light between the wave front sensors (reflection) and CONICA (transmission). Currently, only two dichroics are offered; the remainder will be offered in future periods.

2.2. CONICA

CONICA takes the corrected beam from NAOS and can be used for

- imaging with 34 broad, intermediate and narrow-band filters,
- low-resolution long-slit spectroscopy with four grisms,
- polarimetry with Wollaston prisms or wire grids,
- coronography with masks in the focal plane and apodising masks in the pupil plane and
- Fabry-Perot imaging.

There are seven objectives in the camera wheel, which allow one to do all of the above at pixel scales ranging from 13 to 110 milli-arcseconds per pixel.

The array is an Aladdin detector and is sensitive over the 1–5 micron wavelength range. Depending on which elements are in the light path, the background on the array can vary by six order of magnitude. To cope with this, a number of readout modes and bias voltage settings are used.

The total number of instrument and detector configurations is very, very large. Currently, only a small subset of all possible configurations are offered. Additional configurations will be offered as their usefulness are assessed.

3. NOAS-CONICA (VLT) Operations

NAOS-CONICA is operated like any other instrument on the VLT, so when one refers to NAOS-CONICA operations, one is really referring to VLT operations (Hanuschik et al. 2002; Mathys et al. 2002; Quinn et al. 2002, Silva et al. 2002). Given the number of instruments on Paranal, their complexity and the number of operators who are likely to operate any one instrument, a successful and efficient operation demands a very high degree of uniformity in instrument operations.

Operations are guided by the following principles:

- All observations and calibrations are done with Observing Blocks (OBs).
- All calibrations are done by the observatory staff according to a calibration plan.
- Daily tasks are managed through checklists.
- Instrument (and telescope) performance is monitored and recorded.
- All data is checked and archived.

3.1. Observing Tools - The Life-cycle of an OB

The astronomer and the observatory have a number of tools to prepare and execute observations, to monitor instrument performance and assess data quality. These tools are illustrated in Figure 2, where we follow the life-cycle of an OB.

After carefully reading the User Manual and the Calibration Plan, the astronomer uses the preparation software (PS) to determine the optimal configuration of NAOS for a given set of observing conditions and reference parameters, the Exposure Time Calculator (ETC) to compute S/N estimates and the phase II preparation (P2PP) tool to prepare OBs.

The astronomer specifies under which conditions the observations should take place. Constraints generally include the seeing, the transparency of the atmosphere, the airmass, the distance to the moon and the lunar phase. For

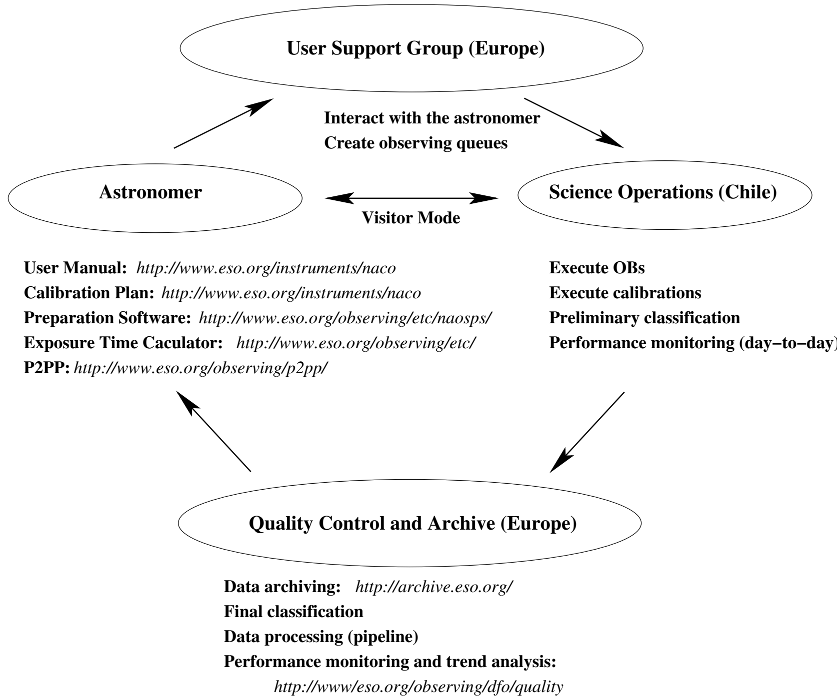

Figure 2. The life-cycle of OB, from creation by the astronomer, scheduling by USG, execution in Chile, and archiving in Europe.

observations with NAOS-CONICA, the user also lists the Strehl ratio, which is a measure of the quality of the correction. The Strehl ratio is determined by the PS, and it depends on the characteristics of the atmospheric turbulence, the brightness and morphology of the reference source and the distance of the reference source to the target. The use of PS is obligatory for all NAOS-CONICA observations. It is discussed in more detail in Section 3.3.

In service (queue) mode, the OBs, the finding charts and a file describing the observations are submitted to the User Support Group (USG) in Europe. USG checks the validity of the submitted material and inserts the OBs into queues that are updated on a daily basis. In visitor mode the OBs are usually prepared a few days before the observations take place. In this case, USG and QC are not directly involved, but all data is still archived. The OBs, whether it be service or visitor mode, are executed by ESO staff in Chile. Calibrations are taken the following day according to the calibration plan.

In service mode, OBs are started if the seeing, airmass, etc., are with the limits specified by the astronomer. At this point, there is no information about the Strehl ratio. This is evaluated during the acquisition of the target and during execution of the OB, both through direct measurements on the data (if possible) and through inferred estimates provided by the real time computer, which is the computer that measures the wavefront distortions and controls the tip-tilt and deformable mirrors. The operator assigns a preliminary classification according to measured or inferred Strehl, airmass, etc. Three classification classes are used: A - meets all specifications, B - does not meet all specifications but should not be repeated, C - does not meet all specifications and should be repeated. In general, the seeing is not used to classify OBs.

OBs that were classified as C are immediately re-queued. The data from OBs that were classified A or B are examined by quality control in Europe, where a final classification is made. These OBs can be reclassified as C and, as such, will be re-queued. All data, regardless of the classification, is archived and passed onto the user. The data is usually sent to the astronomer once the program is complete and is available to the entire community one year later.

The performance of the instrument is monitored by the observatory staff on a daily basis. All information is collected into a central database which can be queried. The database contains information from telescope and instrument subsystems, pipeline processing of the data and the meteorological station. The monitoring is primarily designed to detect sudden changes in instrument performance. The performance of the instrument is also monitored in Europe. Here, the emphasis is on long term trending. Results are fed back into the system as improvements to operations.

3.2. The NAOS-CONICA Calibration Plan

The calibration plan is an important document and this is particularly true for a complex instrument like NAOS-CONICA, where the number of modes is very large and the amount of time to do calibrations can be limited. The calibration plan describes:

- which calibrations are supported, and which are not,
- how they are done,
- how frequently they are done,
- how accurately they are done, and
- how they are processed, if some sort of processing is required.

Twilight flats provide a pertinent example of what is in the calibration plan. In principle, with 7 objectives, 34 filters, 3 neutral density filters and 5 dichroics, one could have $7\times\ 34\times\ 3\times\ 5 = 3570$ combinations. To calibrate all possible combinations is an impossible task. As an alternative, twilight flats are taken with a single dichroic and without neutral density filters. The calibration plan states this and discusses how useful the flats are if a different dichroic or a neutral density filter was used during the observations. All of this needs to be tested and characterized during *Paranalization*.

3.3. The Preparation Software

In addition to the standard observing tools, such as P2PP and the Exposure Time Calculator (ETC), users have to use the preparation software (PS).

As input, the PS takes:

- the wavelength of the observation,
- the seeing (at Zenith) and airmass of the observation,
- the brightness and morphology of the reference source,
- the spectral type or black body temperature of the reference source,
- the distance between the reference source and the scientific target and
- any user constraints (if any) that the user sets with regards to the configuration of NAOS.

Table 1. The future of adaptive optics at the VLT.

Instrument Name	Purpose	Year
Laser Guide Star	For NAOS-CONICA and SINFONI	04
MACAO (6 will be built)	Curvature sensing AO system	02–04
MACAO + SPIFFI (SINFONI)	AO assisted 3D system IR Spectroscopy	02–04
MACAO + CRIRES	AO assisted high resolution IR Spectroscopy	04
MAD	Multi-conjugate AO Demonstrator	04

As output, the PS delivers:

- the Strehl ratio on the target and the reference source at the wavelength of observation,
- the Strehl ratio on the reference source at 2.16 microns (this corresponds to the wavelength of the Br_γ filter),
- a model PSF which is used by the ETC for estimating exposure times,
- the optimal NAOS configuration, and
- a P2PP parameter file containing all of the above information.

In this way, the user does not need to know anything about NAOS.

The PS consists of a PS GUI and a PS server. The PS GUI is available from the ESO web pages.[2] The server receives requests from the GUI, does all the necessary calculations and sends the results back to the GUI for inspection.

Currently, three servers are running: one in Europe for OB preparation, one in the control room for real time OB preparation, and one on the instrument workstation for real time optimization of NAOS. Real time optimization is the default mode of operations.

The estimate of the Strehl ratio provided by the PS is critical, since it is compared directly to the one measured in the data. The two values are compared and the OB is classified accordingly. If the PS over-estimates the performance of NAOS, very few OBs will be successfully executed according to the rules which are currently in use.

4. Adaptive Optics at the VLT: Future Prospects

Over the next few years, ESO will install, commission and operate a number of facilities/instruments that are either AO systems or will be feeding to/from AO systems. The instruments and their commissioning dates are listed in Table 1.

As these lines are being written, NAOS-CONICA has been in operations for six weeks. The experience in operating NAOS-CONICA, the first AO system at the VLT, should prove to be very useful in optimising the operations of the many AO instruments to come.

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

References

Hanuschik, R. W., Hummel, W., Sartoretti, P., & Silva, D. R. 2002, "Quality Control of the ESO-VLT instruments," in Observatory Operations to Optimize Scientific Return III, P. J. Quinn, ed., Proc SPIE 4844, in press

Lacombe, F., Zins, G., Charton, J., Chauvin, G., Dumont, G., Feautrier, P., Fusco, T., Gendron, E., Hubin, N. N., Kern, P. Y., Lagrange, A. M., Mouillet, D., Puget, P., Rabaud, D., Rabou, P., Rousset, G., & Beuzit, J. 2002, "NAOS: from an AO system to an astronomical instrument," in Adaptive Optical System Technologies II, P. L. Wizinowich, ed., Proc SPIE 4839, in press

Lenzen, R., Hartung, M., Brandner, W., Finger, G., Hubin, N. N., Lacombe, F., Lagrange, A., Lehnert, M. D., Moorwood, A., & Mouillet, D. 2002, "NAOS/CONICA first on sky results in a variety of observing modes," in Instrument Design and Performance for Optical/Infrared Ground-Based Telescopes, A. Moorwoed, ed., Proc SPIE 4841, in press

Mathys, G., Gilmozzi, R., Hurtado, N., Kaufer, A., Lidman, C. & Parra, J. 2002, "Paranal science operations: running the four 8m unit telescopes of ESO's VLT" in Observatory Operations to Optimize Scientific Return III, P. J. Quinn, ed., Proc SPIE 4844, in press

Quinn, P. J., Gilmozzi, R., Comeron, G., Mathys, G., & Silva, D. R. 2002, "VLT end-to-end science operations: the first three years," in Observatory Operations to Optimize Scientific Return III, P. J. Quinn, ed., Proc SPIE 4844, in press

Rousset, G., Lacombe, F., Puget, P., Hubin, N. N., Gendron, E., Fusco, T., Charton, J., Feautrier, P., Kern, P. Y., Lagrange, A. M., Madec, P. Y., Mouillet, D., Rabaud, D., Rabou, P., Stadler, E., & Zins, G. 2002, "NAOS, the first AO system of the VLT: on-sky performance," in Adaptive Optical System Technologies II. P. L. Wizinowich, ed., Proc SPIE 4839, in press

Silva, D. R. 2002, "Service Mode Scheduling at the ESO VLT," in Observatory Operations to Optimize Scientific Return III, P. J. Quinn, ed., Proc SPIE 4844, in press