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Auxiliary Telescopes at Dome C

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Abstract: The Auxiliary Telescopes (AT) designed and manufactured by AMOS S.A. are part of the VLT Interferometer (VLTI) located on Cerro Paranal - Chile. Two of four are available for regular observation with the MIDI instrument from October 2005.
These 2 m-class turn-key telescopes are autonomous, with their enclosure, air conditioning, translating and positioning system, etc. Their dedication to interferometry is present at each level of design, manufacturing and testing.
The exciting perspectives of observation conditions at Dome C - Antarctica promote that site as one of the best candidates to install the next generations of terrestrial optical arrays.
The knowledge acquired with the Auxiliary Telescope System (ATS) could greatly help to make the good choices in the early months of a new interferometer development. This article presents an overview of the main features of the ATS and its adequacy with Atacama desert conditions. The *winterisation* consists in making it operational in Antarctic conditions: this is of special concern to the concept, the engineering, the technologies, the testing and the deployment. The aim is to judge the effort to bring the auxiliary telescopes on top of Dome C.

Keywords: Optical Array, Interferometric telescope, Dome C, Antarctica, Very Large Telescope, VLTI, Auxiliary Telescopes System, *Winterisation*.

1 Introduction

First fringes were obtained with AT#1 and AT#2 on February 2-3, 2005. The coming of the AT's greatly extends the capabilities of the VLTI thanks to the numerous possibilities of observation configurations (baselines) by positioning any pair of telescopes on two of the 30 observation stations distant up to 200 m from each other. The Auxiliary Telescopes much increase observation time of the VLTI thanks to their versatility and their exclusive operation together with the interferometer.
The specificity of the AT requirements and design originates from their dedication to interferometric observations down to visible wavelengths. This calls for a mechanical stability at the nanometer level together with the capability to relocate the telescope in an autonomous way. The constraints of integration, compactness and weight are similar to what is expected in the design of a vehicle.
In the light of the experience of the VLTI, one can consider if a concept similar to the ATS can be transposed to an optical array settled on Dome C, Antarctica. For that purpose, the main

Figure 1: Aerial view of Paranal Observing Platform with AT#1 and AT#2 (G. Hüdepohl, ESO)

features of the ATS are presented and the Paranal environmental conditions are compared to Antarctica. Finally, the main topics of the *winterisation* are developed.

2 ATS Design Overview

The ATS is composed of four identical Auxiliary Telescope Units that can be plugged on any of the 30 anchoring stations distributed on the observation area of Paranal (see Figure 1). The AT's can be relocated from one station to any other in less than 3 hours without re-alignment.

The AT is self-contained and autonomous. It includes:

- The telescope, supporting all the optics (M1 to M11) that collect the stellar light and send it to the interferometric laboratory. It is a 2 m-class (aspherical) Ritchey-Chrétien telescope on an Alt-Azimuth mount. The Altitude axis is 5 m above the ground. The motors are direct drives and the bearings are mechanical;
- The so-called transporter, able to carry the telescope from one observing station to any other one in an autonomous way;
- The enclosure, protecting the sensitive parts of the AT against adverse environmental conditions;
- The ATS control system controlling all the electro-mechanical functions of the ATS by means of appropriate hardware and software.

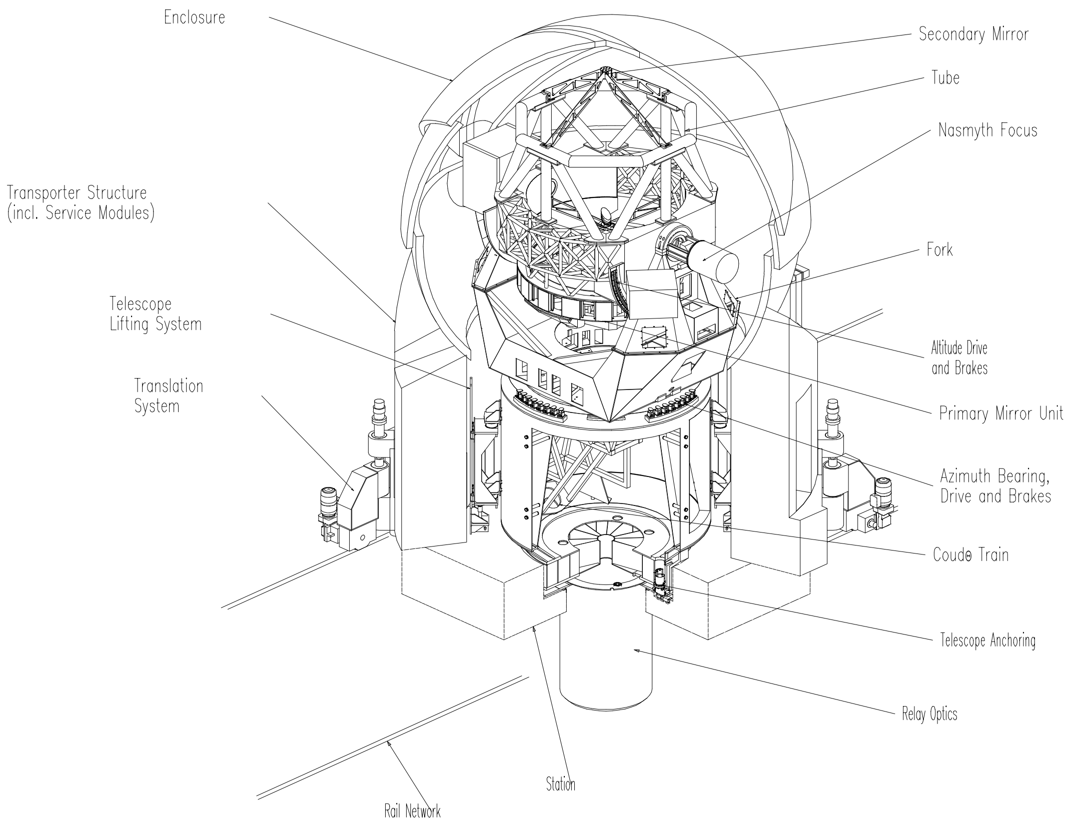

Figure 2: Auxiliary Telescope anchored on a station

Wavefront quality of the whole telescope in operation:	< 110 nm r.m.s. WFE including focus errors < 90 nm r.m.s. WFE without focus errors
Wavelength range:	0.4 to 25 μm
Telescope position repeatability:	±10 arcsec, ±0.1 mm after any relocation
First telescope eigenfrequency:	> 10 Hz
Pointing accuracy:	< 1 arcsec r.m.s. (whole sky)
Tracking accuracy (blind):	< 0.1 arcsec r.m.s.
Tracking accuracy (field stab.):	< 0.025 arcsec r.m.s. (mv=13)
Optical Path Length (OPL) stability:	< 30 nm rms over 10 msec < 70 nm rms over 48 msec < 300 nm rms over 290 msec
Total mass:	< 30 Tons
Design volume:	H < 7.1 m, W < 5.4 m & L < 5.8 m

Table 1: Main AT performance requirements

The design driver parameters are:

- OPL stability under dynamic wind load, seismic activity and internal vibration sources (bearings, drives, possibly pumps, fans,...)
- Pointing / tracking accuracy especially at low speeds when stick-slip effect occurs
- Image quality requiring modern polishing techniques, optimised opto-mechanical design and good thermal control during daytime

Figure 3: Primary mirror in its cell

Figure 4: AT#1 on the Paranal observation area at sunset

The environmental conditions are taken into account at every step of the development: from earthquake survival dimensioning to choice of part, materials and process of manufacturing. In a remote location as Paranal, the reliability and the maintainability are acute.

3 Environmental Conditions: Paranal vs Dome C

As a starting point, one can compare the conditions encountered on both sites. Obviously, the temperature is the most difficult constrain to deal with but in the *winterisation* process, all the constraints should be kept in mind in order to make the good choices from the beginning of the development.

	Paranal - Atacama desert, Chile	Dome C, Antarctica
Air pressure:	750 hPa (altitude 2600m)	645 hPa (altitude 3280m)
Air temperature range:	operational: 0°C to +15°C functional: -10°C to +25°C low seasonal variations	-50°C (down to -85°C) in winter extreme seasonal variation (> 40°C)
Relative humidity:	5 to 15%	Extremely low relative humidity
Wind speed:	full performance up to 10 m/s reduced performance up to 18 m/s survival up to 47 m/s	2.8 m/s mean 16 m/s max
Precipitation:	sporadic precipitation	snow yearly precipitation range: 2-10 cm
Ground stability:	survival to earthquakes (several / year)	ice shearing: 1 cm/km/year, no solid rock for foundation
Others:	UV irradiation	UV irradiation

Table 2: Environmental conditions at Paranal and Dome C

4 Winterisation

The winterisation will consist in making an instrument compatible with the Antarctic climate. The size of the telescope and all its constituting components is determining the complexity of the task. This process will start from the conceptual design phase. Some basic issues will be worked out very early at the system level:

- Movable telescopes: the complexity in total remote operation should be balanced with the scientific benefit.
- The enclosure functionality should be reconsidered since the conditions of seeing, wind, etc are not comparable to any other site.
- The stability of the ice-based stations is an important issue: this impacts not only the telescope behaviour but also the delay line and the instrument. A good characterisation is therefore essential. The control of the stability should be managed by combination of hardware and software techniques.
- Again, the thermal conditions at ground level need to reconsider the beam transport principle. For example an ice tunnel could be an option with or without vacuum pipe.
- The possibilities of civil work are basically different: they are very limited but the ice can be used as raw material for certain applications.

In a second phase, some specific engineering issues must be solved:

- The mechanical structure thermal stability must be attained by proper material selection and re-engineering to withstand the large temperature variations.
- The opto-mechanical study of the mirror supporting should be re-assessed using the similar approach as space cryogenic telescopes design.
- An advanced thermal management is necessary to take advantage of the very low temperature of the site for Infrared observation. This includes the power saving, remote electronics away from the optical path, optimisation of the power extraction. The surfaces temperature should be assessed accurately thanks to finite elements models and computational fluid dynamics (CFD).

Figure 5: AT#1 Secondary mirror and hexapod in-situ

In many cases, the selection of electro-mechanical components, material and consumables must be validated by qualification testing. The bearings, the main drives, the sensors (especially the encoders), the mechanisms as an hexapod or a tip-tilt, the cable-wrap, a filter wheel, a shutter, the brakes, the dampers, the electrical switches, etc are every one potentially subject to loss of performance in Antarctic conditions. For the simplest components, the best approach consists in testing on the shelf components and selecting the most appropriate. For more complex components, some qualifications shall be conducted in collaboration with the manufacturer in order to adapt what was done in more classical applications.

5 Testing in Europe

The testing philosophy of the ATS aimed to validate by test all the performance requirement fulfilment before shipment: bearing friction, modal test, main axis dynamic response, pointing error, OPL stability in operation, tube deflection, image quality and sky test. The AT was made fully operational and extensively tested in Liège, Belgium. Several dedicated support equipments were developed for that purpose. This is a huge investment in hardware, manpower and time but this confers reliability, confidence and shorter installation process on site.

Any large equipment installed on Dome C shall be set-up with a minimum effort and shall be

Figure 6: Auxiliary Telescope Sky Test in Liège

- more than anywhere else on earth - extremely reliable. For these two reasons, the testing in Europe is decisive for the accomplishment of such a challenging project. The major issue lies in the verification of the performance under representative environmental conditions. A possible way to produce very low temperatures shall be in using an existing vacuum chamber made for space borne equipment testing.

The beforehand qualifications of components or critical technologies are probably the most important because they offer the opportunity to improve.

Figure 7: AT#4 on test station at AMOS

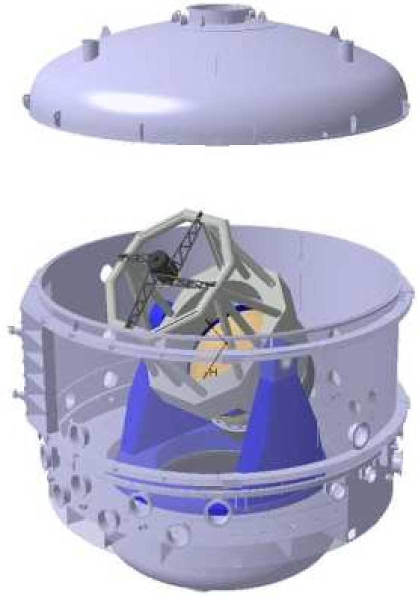

Figure 8: 2 m-class telescope in a vacuum chamber developed by AMOS

6 Deployment Strategy

The access to the Dome C and the working conditions on site leave no place to the extemporisation. At first, the transport by sea and on the ice necessitate compact packaging that can be handled easily. The telescopes shall be designed to minimise the on-site assembly duration. The number of sub-systems shall be minimised, all the optics integrated and pre-aligned before shipment.
Each AT is packed in only four large crates and one 20' container for the small pieces. After 6 weeks on the sea, the crates are transferred by truck to the Cerro Paranal. The pieces are unloaded at the base camp were the AT is assembled and functionally tested in 2 months. Then, the AT is moved to the observation area a few hundreds meters higher. The AT is commissioned after one month of extensive test. It demonstrates that very complex equipment can be made operational in a short time with a minimum of support equipment if the deployment is taken into consideration from the beginning and if it is completely tested before shipment.
The Antarctic condition of operation and maintenance shall be analysed as well. The limited

Figure 9: AT on-site deployment (unloading at the base camp, transfer to the observation area and commissioning)

manpower and support equipment, the limited capacity of the service module and the arduous conditions for repair and maintenance call for high reliability at any level. The instrument should be operated remotely from the site. Given that the access to the site is possible only in summer, the maintenance shall be developed on a 12-month basis. The stand-by mode must be carefully considered since the instrument would stay several months per year in that state. Some facilities shall be developed for the coating of the mirrors. A survey of the material and components ageing is necessary over the lifetime of the instrument.

7 Conclusions

Obviously, the AT's couldn't be installed at dome C but the experience of AMOS S.A. in the design of telescopes dedicated to interferometry is of great interest for the development of a new optical array.

Multi-discipline feasibility studies must start soon to evaluate mechanical conceptual design, verify the compatibility of existing components with low temperature, define a realistic qualification test plan, determine a deployment strategy and proceed to a cost evaluation.

More and more information and data are now gathered from the teams present at Dome C. They are the starting point of further investigation, new perspectives and new challenges.

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