YEPUN (UT4)

The fourth Unit Telescope (YEPUN) is now in the final phase of mechanical assembly. Acceptance tests with the supplier will start soon, after which the construction of the four telescope structures will have been finished. The fourth M1 Cell arrived at Paranal in late August (Fig. 5). "First Light" for YEPUN is scheduled for July 2000.

VLTI

In Europe, major achievements occurred in the area of the VLT Interferometer (VLTI) construction. The two siderostats are being tested on the cloudy European sky (see article by F. Derie et al. in this issue). ESO concluded a contract with REOSC (France) for delivery of all mirrors to equip the four VLT Unit Telescopes with coudé foci optics. An important milestone was reached with the completion of the polishing of the optics for the first delay line for the VLTI at REOSC. The integration of the cat's eye will be done at TNO (Netherlands) and this part will then be integrated into the delay line at Fokker Aerospace (The Netherlands). Shipment to Chile will take place immediately afterwards. In addition, the 1.8-m primary mirror for the first VLTI Auxiliary Telescope has reached the final stage of the light-weighting process and the optical polishing will soon begin at AMOS (Belgium). The already manufactured optics (null correctors, M2 matrix) have shown excellent optical quality results. A contract for the purchasing of the Auxiliary Telescope number 3 was concluded with AMOS.

The "Residencia"

It has always been ESO's intention to provide better quarters and living facilities at Paranal. Plans for the design and construction of the "Facilities for Offices, Board and Lodging", also known as the Paranal Residencia and Offices, were therefore begun some years ago. The project was developed by Auer and Weber Freie Architekten from Munich (Germany). Their design was selected among eight proposals from European and Chilean architects.

The unusual conceptual design is structured as an L-shaped building, located downhill from the Paranal access road on the southwest side of the present Base Camp. The building is fully integrated into the landscape, essentially underground with its southern and western facades emerging from the ground, providing a view from the bedrooms, offices and restaurant towards the Pacific Ocean. The common facilities, restaurant, offices, library, reception and meeting rooms are articulated around the corner of the building, while the hotel rooms are distributed along the wings of the L-shape. A circular hall, 35 m wide and four floors deep – covered with a dome emerging at ground level – is the building's focal point with natural light. At the floor of the hall there is an oasis of vegetation with a swimming pool. Special protection against light pollution is foreseen. To a large extent, the ventilation is with natural airflow through remotely controlled air in outlets.

The Chilean firm Vial y Vives won the construction tender. Work on the first part of the building began on July 1, 1999, and is scheduled to be completed within two years. The excavation work for the Paranal Residencia is proceeding according to schedule, with the first concrete to be cast shortly.

Performance of the VLT Mirror Coating Unit

E. ETTLINGER (LINDE), P. GIORDANO and M. SCHNEERMANN (ESO)

In August 1995 ESO signed a contract with LINDE AG to supply the coating unit for the mirrors of the Very Large Telescope. The coating unit was first erected and tested in Germany and then disassembled, packed and shipped to Chile. After integration into the Main Maintenance Building on Paranal, the first mirror was coated on May 20, 1998 ("First Light" on May 25–26, 1998). The final runs for provisional acceptance were performed in January 1999.

The Coating Unit

The Coating Unit encloses the following main components (see Fig. 1):

• the vacuum chamber with a diameter of more than 9 m and an inner volume of 122 m^3

• the roughing pump system and the high vacuum pumping system, consisting of 8 cryo pumps and a Meissner trap

• the mirror support system, a whiffle tree structure with lateral and axial pads to support the glass mirror during coating

• the mirror rotary device including a ferrofluidic vacuum feedthrough, to rotate the mirror underneath the magnetron during coating

• the coating cart, enclosing an air cushion system to drive the lower chamber section and a lifting device, to close the vacuum chamber after mirror loading

• the magnetron sputter source with a water-cooled shutter system and cryogenic shields

• the glow discharge cleaning device, to heat up and clean the mirror surface prior to coating.

Thin Film Deposition Equipment

The main component for the coating process is the thin film deposition equipment of the Coating Unit comprising the following components:

• sputter source for aluminium including power supply

• shields to trim the aluminium coating deposited

• shutter panels

• cryo panels attached to the shutters

• Glow Discharge Cleaning Device (GDCD) including power supplies

The DC Planar Magnetron Source consists of the target 99.995% pure aluminium cathode bonded to a water-cooled backing plate to reduce the heat radiated to the mirror. The discharge is produced by the use of an inert gas (Argon) to support the flow of current between cathode and anode. The planar magnetron source uses magnetic fields to focus electrons in the region of the sputtering target.

Stainless steel trim shields, which are placed below the cathode to trim the deposition of the sputtered aluminium, ensure that the mirror is evenly coated with a uniform thickness of aluminium.

The shutter panels are stainless steel sheet box constructions, which are cooled by water, fed through the panels under pressure. There are two shutters, one to form the leading edge of the coating, and one to form the trailing edge. Both shutters are pivoted about the centre of the mirror, and at the beginning of a coating run both shutters are closed together along the line of the joint band.

Below the shutter panels, copper cryo panels are suspended, filled with liquid nitrogen.

Their purpose is to provide an area of high purity and homogeneity between the shutter opening below the magnetron and hence aid and improve the quality of the reflectance of the aluminium deposited onto the mirror.

The GDCD consists of two aluminium electrodes, shaped to give the required profile. The glow discharge electrodes are water-cooled and are suspended from a dark space shield, which is also made of aluminium. The purpose of the GDCD is to reduce adsorbed water molecules from the mirror, the inner surfaces of the chamber and all components mounted inside the chamber. The

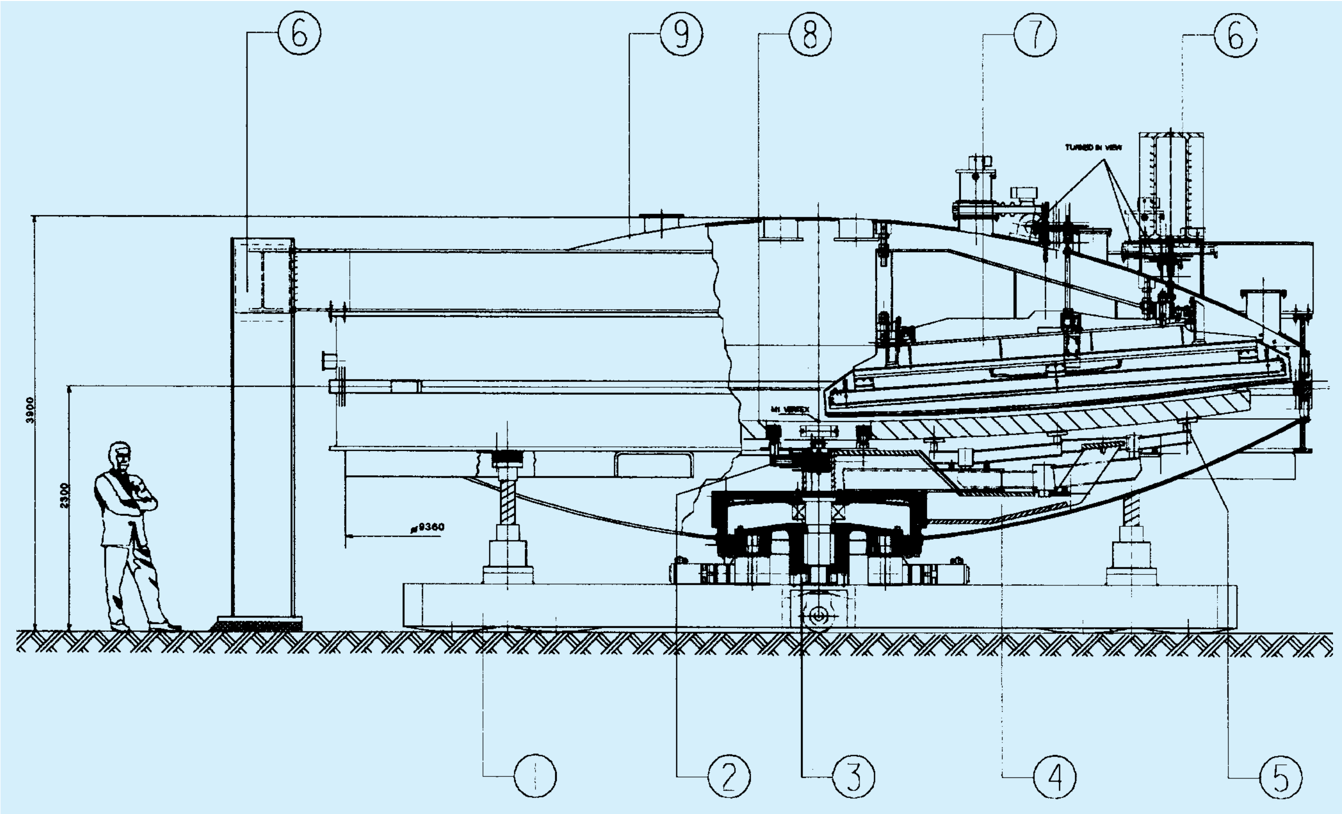

Figure 1: Main components of the VLT Coating Unit. Cart chassis and drive (1), Lateral pads (2), Mirror rotary device (3), Mirror support system (4), Axial pads (5), Supporting frame (6), Magnetron, shield and shutter (7), M1 mirror (8), Vacuum vessel (9).

glow discharge also heats the mirror surface, which improves film adhesion and film purity.

Process Description

The method selected to deposit a thin aluminium film on the mirror is the sputtering process.

The sputter coating process is done by inserting a mirror into a vacuum chamber, which contains a specially designed cathode and an inert process gas. A negative voltage is applied to the cathode (target) and a glow discharge (plasma) ignites within the vacuum chamber when the appropriate environment (or conditions) are achieved.

At this point, positively charged atoms of the gas (ions) are attracted to the surface of the target which is negatively charged. The positive atoms strike the negatively charged target with such force that atoms of the target are ejected and deposited on the mirror surface, building up a thin layer atom by atom.

What differentiates a magnetron cathode (used here) from a conventional diode cathode is the presence of a magnetic field which confines electrons in the region of the sputtering target. A magnetic field is supplied from below the cathode target, which is arranged so that free electrons are captured in the crossed magnetic and electric fields in the region. The captured electrons enhance the ionisation in the inert gas atmosphere. Overall, the effect is to lower the operating voltage required, from several kilovolts to less than 1000 volts. The most striking gain of the magnetron design, however, is an order-of-magnitude increase in coating deposition rates per unit area of target.

Figure 2: The lower part of the coating unit vacuum chamber. For loading and unloading of the mirrors, the lower half of the chamber is moved on 8 air-cushions from the coating unit location to the mirror handling tool and vice versa.

Coating Procedure

The mirror is loaded into the lower half of the coating unit. The two halves of the vacuum chamber are brought together, sealing the coating unit. Then the chamber is pumped down to achieve the required vacuum level.

The mirror is rotated beneath the sputter source and GDCD so that it can first receive a surface treatment and then its coating of Aluminium.

After the surface treatment via the GDCD has been completed the magnetron is powered up to pre-sputter until the cathode’s surface is clean.

The mirror is rotated at a pre-determined speed calculated to give the intended coating thickness at the intended

Figure 3: A look into the coating unit vacuum chamber. The upper vacuum chamber part carries the DC planar magnetron sputter source. In the lower part the rotatable whiffle tree for support of the primary mirror is visible.

sputtering rate. The leading edge shutter is opened as the intended position of the joint band passes underneath. Thereby, the rotational speed of the shutter exactly matches that of the mirror.

After the mirror has completed one revolution, the trailing edge shutter is closed by rotating it at the same rotational speed as the mirror, as the film joint passes underneath. This produces sharply stepped edges to the coating, the trailing edge lying on top of the leading edge. Shadowing of the coating by the shutter edges prevents them from being perfect steps.

Because both shutters are pivoted about the centre of the mirror, all points along the joint band take the same time to cross the mirror opening.

Figure 4 shows an overview of the pressure conditions inside the coating chamber during the glow discharge cleaning treatment of the mirror and the sputter process. Prior to glow discharge cleaning, the chamber is pumped down to less than 0.001 Pa. Then air is fed in and at a pressure of 2 Pa (cryo pumps throttled) the GDC process is started. After the mirror has completed one revolution, the glow discharge cleaning is finished and the chamber is pumped down to less than 0.0002 Pa within less than 10 minutes, which demonstrates the high pumping speed of the high-vacuum pumping system. Finally, argon is fed in and sputtering is started at an argon pressure of 0.08 Pa.

Test Procedure

During the tests of the coating unit the M1 mirror was replaced by the dummy substrate, a test platform which represents the surface of the M1 mirror. It allowed the mounting of glass slides (50 × 50 mm, 1 mm thick) onto which the aluminium coating was deposited.

Up to 60 glass slides were mounted onto the dummy substrate at intervals along the M1 radius. The position of the slides was recorded on the back of the slides, together with the coating run number.

During a long experimental phase, which covered more than 30 test runs, the following parameters were optimised:

• pressure of the argon process gas
• clearance between aluminium target and mirror surface
• adjustment of shutter for an extremely small joint line
• rotation speed of mirror rotary device.

The influence of the glow discharge cleaning device was investigated with respect to the film adhesion and reflectivity of the samples. In addition, the temperature raise on the sample surface was measured during glow discharge cleaning treatment and coating.

The optimisation goal was:

• a film thickness of 80 nm with a thickness uniformity of 5%
• a sputter rate of 5 nm/s at 80% of the mirror surface
• the best possible reflectance of the aluminium film in the wavelength range between 300 and 3000 nm.

Aluminium Film Reflectance

After coating in the VLT Coating Chamber, the reflectance of the samples was investigated in a reflectometer with an accuracy of about 0.1%. The reflectance measurement was absolute, not relative to a standard material whose reflectance must be known.

The reflectance data of the samples were compared (see Fig. 5) with two reflectance standards:

• The reflectance standard used in the USA: “Standard Reference Material 2003, Series E”, issued by the National Institute of Standards and Technology (NIST).
• “Infrared Reflectance of Aluminium Evaporated in Ultra-High Vacuum”, published by Bennet et al. in *J. Opt. Soc. Am.* 53, 1089 (1963).

Figure 5 shows the absolute reflectance versus the wavelength of the coated samples (solid line) in the ultraviolet, visible and infrared region. The circles (filled and not filled) represent the experimental points measured by Bennet (fresh and aged samples), while the asterisks represent the reflectance according to the US NIST standard.

Over the whole range from 300 to 2500 nm the results obtained in the VLT Coating Chamber are between the aged and not-aged Bennet data and are clearly above the NIST data.

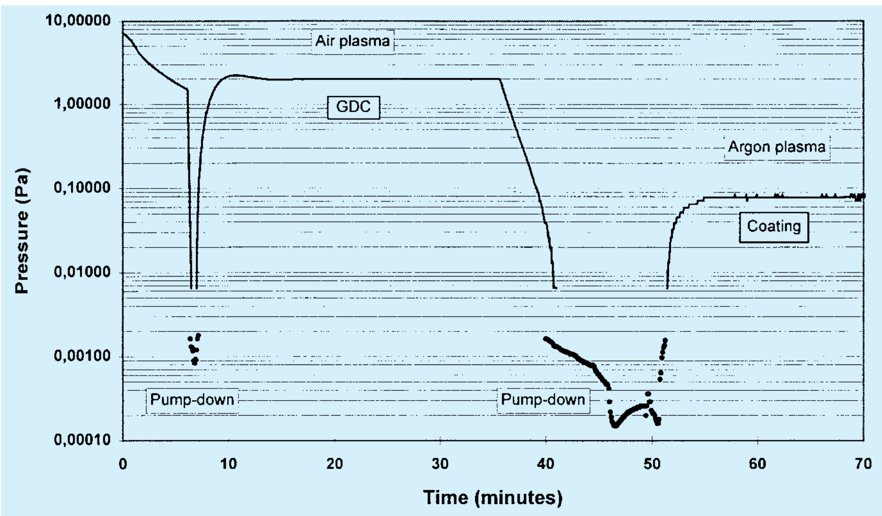

Figure 4: Chamber pressure during GDC- and coating process. After the GDC treatment, the high vacuum pump system pumps down the pressure inside the coating chamber (volume 122 m^3) from 2 Pa to 0.00015 Pa in less than 10 minutes.

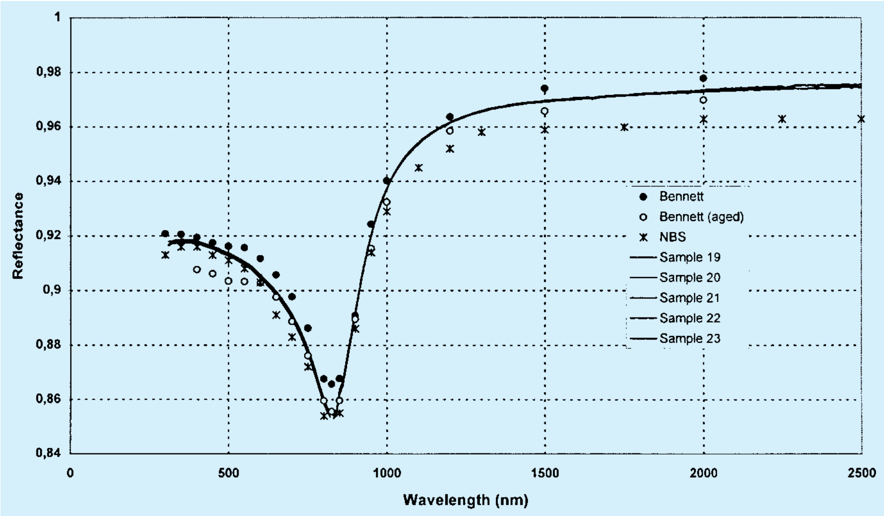

Figure 5: Measured reflectance values of coated samples (5 × 5 cm) as function of the wavelength in the range from 300 to 2500 nm (ultraviolet, visible, infrared). The results of the VLT Coating Unit are compared with the US standard NIST data and best possible measurements in a small laboratory system (Bennet et al. in J. Opt. Soc. Am. 53, 1089 (1963)).

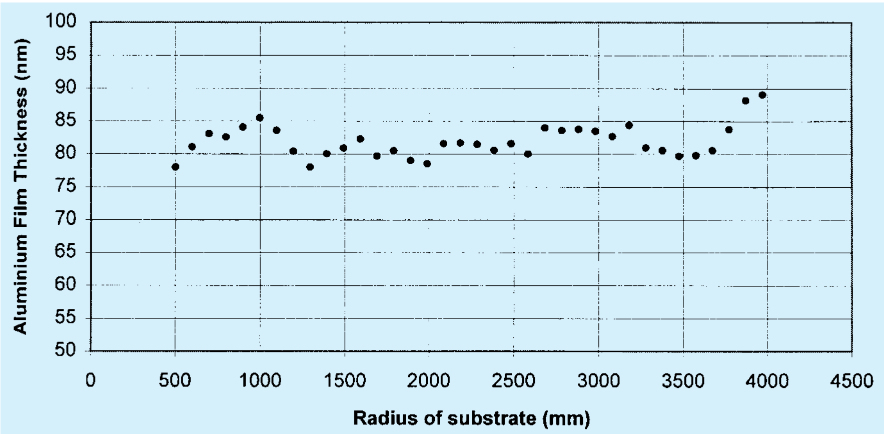

Figure 6: Aluminium film thickness, measured on glass samples along the radius of the mirror. Film thickness mean value 82.48 nm, standard deviation 4.16 % (3.43 nm).

Considering the size of the coating unit (chamber diameter more than 9 m, inner volume about 122 m^3) and the size of the mirror surface (more than 50 m^2) to be coated, the reflectance data measured are excellent.

Bennet's "ideal" data were obtained in a bakeable, grease-free, all-glass, small laboratory system. To reduce the possibility of oxidation of the aluminium during deposition, the evaporation was carried out in an ultra-high vacuum of about 10^{-8} Pa (vacuum inside VLT coating chamber 10^{-4} Pa prior to coating). During the measurement of the reflectance inside a reflectometer, the Bennet samples were flushed with dry nitrogen to minimise the rate of chemisorption of oxygen by the aluminium.

Due to these optimum test conditions Bennet's results are in very good agreement with the theoretically predicted reflectance data for highly pure (99.999%) aluminium and can be considered as the best possible experimental results.

Aluminium Film Thickness

Beside the reflectance, the film thickness of the sputtered aluminium was investigated.

With a special tool a line of coating was removed from the sample. The thickness of the step at the edge of this line was measured in at least three places with a profilometer.

Figure 6 shows the film thickness uniformity along the radius of the mirror (measured at single glass samples). At a mean film thickness of 82.48 nm the standard deviation was 4.16% (3.43 nm). This high film thickness uniformity over a radius of more than 4 metre shows the perfect adjustment of the trim shields and the shutter.

Depending on the magnetron discharge power, a dynamic deposition rate of more than 5 nm per second could be reached.

This rate is the film thickness divided by the time taken for a point on the mirror to cross the shutter opening. If the measured film thickness is δ nm and the mirror rotational speed is ω degrees per second, and the shutter opening is θ, then

$$\text{Rate} = (\delta * \omega)/\theta$$

Film Joint Zone

Special attention was given to the area where the film coverage was finished. The azimuth position of the joint line and the inclination angle with respect to the radius vector were exactly adjusted. The defined shutter control and the shadowing of the coating by the shutter edges resulted in a joint line zone, which could no longer be detected by variations in the film thickness uniformity. The only indication was a slight decrease in the reflectance (see Fig. 7) in the ultraviolet and visible region which could be measured in a band of less than 20 mm width. The reflectance in the infrared spectrum was not noticeably influenced.

Temperature Increase During Coating

In order to measure the temperature raise of the mirror during coating, thermocouples were glued to the bottom

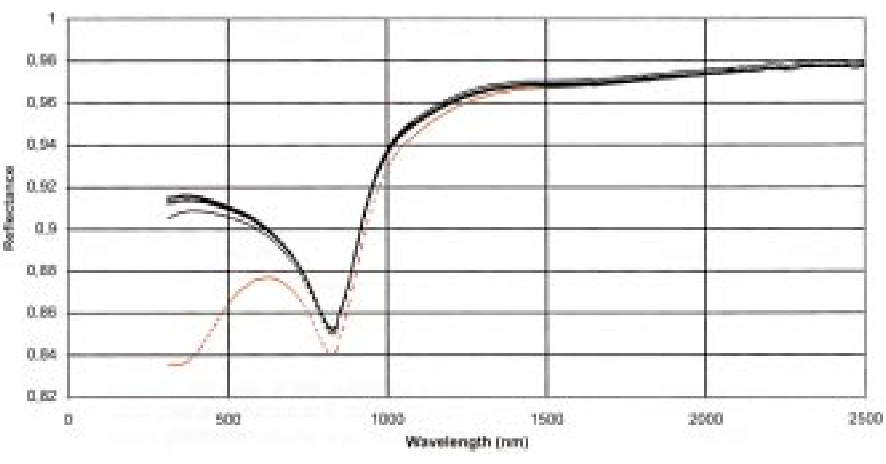

Figure 7: Decrease of reflectance in the ultraviolet and visible region of wavelength inside the joint line of the mirror at a radius of 2.1 m. The dotted lines show the beginning and the centre of the joint line zone, which had a width of less than 20 mm.

side of glass samples. Then they were positioned at 7 different radii and fixed thermally insulated onto the platform of the dummy substrate.

During the passages underneath the magnetron, the temperature increase on the samples could be determined at the same time when the aluminium film grew up.

The result was a temperature raise of less than 10°C on the surface. The samples at the outer radii warmed up more due to their larger clearance to the liquid nitrogen cooled shields underneath the shutter and the larger shutter opening.

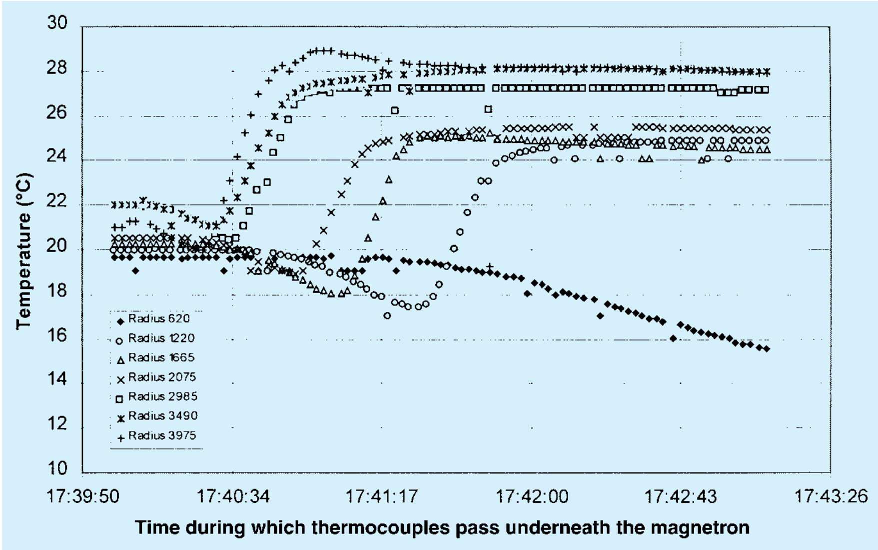

Figure 8: Temperature increase of the mirror surface during coating, measured by thermocouples positioned at 7 different radii and rotated underneath the magnetron. The magnetron discharge power was 102 kW, the rotation speed 20 degree per minute.

Summary

The sputtered aluminium film on the 8-metre-class mirrors produced in the VLT Coating Unit is very uniform along the whole radius (standard deviation 4.16%). The reflectance in the ultraviolet, visible and infrared regions is near to that which ideally can be expected. Furthermore, the dynamic deposition rate, defined as the film thickness cumulated in a single pass of the mirror past the source opening, is higher than 5 nm per second. The shutter system produces sharply stepped edges at the start- and end line of the coating and minimises the joint line to a width of less than 20 mm. All results are within or above ESO specification.

Climate Variability and Ground-Based Astronomy: The VLT Site Fights Against La Niña

M. SARAZIN and J. NAVARRETE, ESO

1. Introduction

Hopes were raised two years ago (*The Messenger* 89, September 1997) to be soon able to forecast observing conditions and thus efficiently adapt the scheduling of the observing blocks accordingly. Important steps toward this goal were achieved recently with the start of an operational service forecasting precipitable water vapour and cirrus (high altitude) cloud cover for both La Silla and Paranal observatories[1]. This was made possible thanks to the collaboration of the Executive Board of the European Centre for Medium Range Weather Forecasts (ECMWF) who accepted to distribute twice a day to ESO the Northern Chile output of the global model. The ground-level conditions[2] are also extracted from the ECMWF datasets with immediate benefits for observatory operation: bad weather warnings could be issued 72 hours in advance during the July snowfalls at La Silla. Once embedded into the Observatory control system, the temperature forecast is due to feed the control loop of the VLT enclosure air conditioning.

These forecast systems still have to be optimised and equipped with a proper user interface tailored to astronomer's expectancies. They might then join established celebrities like the DMD Database Ambient Server[3], paving the way to modernity for ground-based astronomical observing.

2. Unexpected, Improbable and Yet, Real

In this brave new world, however, not everything is perfect: as if the task of building a detailed knowledge of our sites was not hard enough, climatic events such as the El Niño–La Niña Oscillation (*The Messenger* No. 90, December 1997) can turn decade long databases into poorly representative samples. As was reported with UT1 Science Verification (*The Messenger* No. 93, September 1998), the VLT site started to behave anomalously in August 1998. A re-analysis of the long-term meteorological database pointed out an ever-increasing frequency of occurrence of bad seeing associated to a formerly quasi-inexistent NE wind direction. This contrasting behaviour is illustrated in the examples (Figs. 1 to 4) as displayed by the Database Ambient Server. While good seeing occurs under undisturbed NNW flow from above the Pacific, this NE wind is coming from land, it is rapid (Fig. 5), turbulent, and up to 2 degrees warmer than ambient. Finding its exact origin became a challenging task.

3. Searching for Clues

It is commonly stated that observatories are worse when operation starts than they appeared during the proceeding site survey. This is the well-known 3σ effect, the most outstanding site being probably at the top of its climatic cycle when it is chosen. This theory did not apply to the VLT site for which we had records since 1983 showing an impressive climatic stability. Therefore, before accusing *The Weather*, a complete investigation was undertaken, starting with man-made causes. In particular the chronology of the stresses imposed to the site since the construction of the VLT had started (e.g., water sewage, power generation, heat exchanging) were reviewed in collabo-

[1] http://www.eso.org/gen-fac/pubs/astclim/forecast/meteo/ERASMUS/

[2] http://www.eso.org/gen-fac/pubs/astclim/forecast/meteo/verification/

[3] http://archive.eso.org/asm/ambient-server/