THE STATUS OF THE GALILEO NATIONAL TELESCOPE

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ABSTRACT

The Project Telescopio Nazionale GALILEO (TNG) will provide for the Italian astronomical community a 4-m class telescope that closely parallels that of ESO New Technology Telescope (NTT). We describe here its main characteristics and its most relevant differences with NTT, with emphasis on the optical and imaging aspects. The available evidence shows that the optics have an exceptional quality, one of the best ever reached on any large-size telescope. Regarding the site, an agreement has been reached with the Instituto Astrofisico Canario and the Comite Cientifico Internacional to locate the TNG at La Palma, in a site on the West side of the mountain. It will be part therefore of the Observatorio del Roque de los Muchachos, which includes the uk telescopes (2.5m INT, 4.2m WIHT, 10m JHT), the Carlsberg Meridional Circle, the 2.5m NOT and the Swedish Solar Tower.

1. The optics

The optics of the TNG has been made according to the same specifications of the NTT, from the shape and material of the blanks (ZERO-DUR by Schott), to the geometrical constants of the mirrors, and to the contractual requisites (80% of the Encircled Energy from the overall system within 0.30 in the passive mode, and within 0.15 in the active mode). The shapes of the primary mirror M1 and of the secondary M2 are represented by the following curve:

\[ z = \frac{\rho^2}{2R} + AD \cdot \rho^2 + AE \cdot \rho^5 \]

where for the primary

\[ R = -15400 \text{ mm}, \quad AD = 8.15183 \cdot 10^{-10} \text{ mm}^{-2}, \quad AE = \text{negligible} \]

and for the secondary:

\[ R = -4416.7 \text{ mm}, \quad AD = 2.10756 \cdot 10^{-17} \text{ mm}^{-2}, \quad AE = -7.76 \cdot 10^{-20} \text{ mm}^{-3} \]

Alternatively, one could specify the conical coefficient \( K \), equal to:

\[ K_1 = -1.0238 \text{ for M1, and } K_2 = -2.4526 \text{ for M2, with} \]

\[ AD = \frac{1 + K}{4R^2}, \quad AE = \frac{(1 + K)^2}{8R^2} \]

The fast converging trend shown by the improvement curve of M1 during the last months of fine polishing advised to attempt, on a ‘best effort’ basis, a further smoothing in order to reach an intrinsic image quality, produced by the whole optical system, corresponding to a concentration within 0.10 of 80% of the geometric encircled energy EE(80).

This required also a further smoothing of M3. The outcome of both processes are now carefully evaluated.

On the basis of interferometric tests, performed by Zeiss using an He–Ne laser (\( \lambda = 632.8 \text{ nm} \)), the present status of the mirrors can be summarized as follows:

M1: after subtraction of constant, tilt, focus and coma a wavefront aberration of 202 nm RMS has been achieved, corresponding to an energy concentration EE(80) = 0.0424 diameter for 35x35 sampling points. This is the so-called basic quality of the mirror, namely the image quality achieved without resorting to the control of M1. The intrinsic quality, evaluated after subtraction of third order coma, third order astigmatism, triangular coma and quadratic astigmatism, corresponds to a wavefront aberration of 16.6 nm RMS (λ/40) or to a surface smoothness of 8.3 nm RMS. The corresponding energy concentration can be calculated to EE(80) = 0.0744 diameter for 35x35 sampling points.

M2: the secondary mirror is in the stage of final polishing in a fast converging process; at moment, EE(80) is within 0.10.

M3: the tertiary has been smoothed out to better than 8 nm RMS of wavefront aberration. Its figuring has been completed.

Further details are presented in the poster by E.D.Knoll (Galileo optic glances for final tests, this Conference).

Final interferometric testing of the mirrors on the ZEISS supports, and their provisional acceptance, is planned for the next months. Tests are also foreseen with M1 in the telescope cell, in order to reach in the laboratory an evaluation of cell performances. The final acceptance will be with optics mounted on the telescope on the mountain.

There is strong evidence therefore that the quality of the TNG optics is one of the best ever reached in large aperture telescopes.

2. Antares, Analyzer of Transverse Aberrations

ANTARES is an instrument originally designed at ESO for analyzing the aberrations of a telescope; it represents a significant improvement on the classical Hartmann test procedure. Schematically, ANTARES consists of a collimating lens which images the telescope pupil on the Shack-Hartmann grid, a single piece consisting of 30x30 small (0.5mm diameter) lenslets. The light falling on this grid is thus divided into about 400 usable sub-pupils (each representing a specific portion of the telescope pupil) which are imaged on a CCD camera. A reference exposure with a laser diode through the same optical set-up provides a second image, used to calibrate the aberrations of ANTARES itself. The shifts between the two patterns give a quantitative
estimate of the wavefront aberrations in terms of Zernike polynomials.

A portable version of ANTARES has been developed in a collaborative effort between Galileo and ESO. The main features of the new system are: (i) telescope focal ratios: from f/8 to f/35; (ii) data acquisition using a CCD camera controlled by a PC; (iii) data reduction on the same PC in real time (about 25 seconds for read-out of 512 × 512 pixels, 20 seconds for computations).

Further details are given in the accompanying poster by Bhatia, Giani and Rafanelli (The Optics of the TNG, this Conference).

3. The Active Optics System

The TNG Active Optics System (AOS) has been made following the NTT guidelines, but it contains significant differences: the controls have been completely redesigned, and the high frequency tilt of M3 added. The AOS can receive inputs from five sources: the Shack-Hartmann wavefront analyzer camera, the two guiding cameras, the scientific instrument at the focal plane, the elevation encoder, the temperature sensors placed on M1 and on the tube structure.

The first source of error information is used for direct correction of low order wavefront distortion terms, by acting on the elastic modes of the primary mirror and on the alignment of M2.

Focus is actively corrected (with M2) using the SH camera and the reference provided by the scientific instrument and/or the tube temperature information.

Tilt is corrected by the telescope drive system (autoguider) for the part concerning long term drift, and by tertiary mirror tilting for the moderately high frequency part (up to 10 Hz). Error information is directly obtained in the latter case from the two guiding cameras and the elevation encoder.

In order to simplify handling of this amount of information (data, commands, telemetry) and of computations and controls (motors, load cells, encoders), it has been decided to use a network of processors belonging to the Transputer class, to provide embedded hardware and firmware for high level and fast communication. Each node of the network will be able to perform data communication and device control operations. Figure 1 shows the TNG active optics and its main control loops.

More details on the current status of the active optics system are given in two accompanying posters (The Active Optics Subsystem of the TNG, by Bortoletto et al., and: A modular Code for the SH Data Reduction, by Ragazzoni, this Conference).

4. The Telescope Structure

The structure of the telescope (see Fig. 2) has been modified with respect to the NTT in order to provide greater flexibility of operation.

Although the main use of the telescope is foreseen at the Nasmyth f/11 foci, in case of future developments other configurations can be added, in particular a trapped pseudo-Cassegrain focus f/9 (at the M3 position) and a prime focus with corrector. To this end, the tube structure has been straightened (the vertical struts of the NTT being slightly tapered), and the top ring enlarged to an external diameter of 5100mm.

This extra diameter also allows the M3 unit to be extracted from the tube using the crane on the dome. The M2 unit on the upper ring can be replaced either with a prime focus unit or with a different M2 unit. Should the scientific use of the TNG in thermal IR become desirable, a true Cassegrain position (though of limited height below the mirror cell) could actually be reached removing M3 and replacing the M2 unit with a dedicated one.

Due to these requirements of flexibility, M2 and M3 units have been completely redesigned, abandoning the circular symmetry in favor of a more 'boxy' aspect. The advantage is not only of weight saving, but also of easier storage in the building when changing to other configurations. Particular care has been put in the definition of reference points to ensure quick repositioning of the units. Even the cabling connectors have been selected for remote operation. A further addition is a glycol pipe to the top of the tube, to remove heat from any upper source.

This modification of shape implied also to close the angle between the spiders, from the 'canonic' value of 90° to 60°; the implications for the diffraction figure have been carefully evaluated, and shown to be negligible.

The movement of M2 has also been redesigned; it is controlled by 6 high precision screws in a V-shaped configuration. Three piezoelectric actuators, with tilting range of up to 15° and bandwidth higher than 10Hz, have been added to the back of M3.

5. Site and Building

La Palma is one of the best sites for optical astronomy. It belongs to the subtropical belt, characterized by slow subsidence of dry air from high altitudes, due to the Hadley inter-tropical circulation. It is protected, during most of the year, by a permanent anticyclone which prevents access to storms. Thermal convection, induced by the solar radiation, dominates at low altitudes (1000-2000 m), creating on the island a double regime separated by a strong inversion layer. Below this layer the air is humid and dusty, but at the level of the Observatory (about 2400 m), the air is usually very clear and dry. The stability of this system is guaranteed by the relatively cold local oceanic water stream coming from the North, which prevents the extension of thermal convection at higher altitudes.

The wind is typically coming from NW or NE, and the flow does not create problems to the observations because it carries homogeneous, oceanic air. Turbulence can occur, however, when the wind is coming from the Caldera (from the South), since the slope on the southern side is very steep, but this component is not frequent and is generally associated with bad weather.

One of the most attractive astronomical characteristic of the La Palma site is the very high fraction of clear nights, with more than 50% of photometric nights and about 75% available for spectroscopy. Only Cerro Paranal, the site selected for the ESO VLT, in the Chilean Atacama desert, the number of clear nights is significantly higher.
The best period is around May, with almost 90% of photometric nights. During the summer season there are a number of days degraded by dust coming from the sand of the Sahara desert, carried by high altitude winds above the Canary Islands. The temperature is relatively constant, with day-to-night variations of a few degrees while the average night-time variation is within one degree. The yearly night-time excursion is contained between 0°C and 19°C, although some extremes of −8°C have been recorded.

The site of Galileo, on the West side of the astrophysical area, at a level of 2369 m, close to the top of the Roque de Los Muchachos, is in a relatively smooth area, upwind with respect to the NW and NE dominant winds. It is not far from the NOT, where the seeing is known to be good. The uniformity of the local conditions, deduced from the microthermal data of the JOSO–LEST campaign and from the tests carried out for the installation of the NOT, guarantee good seeing conditions also in the location of the Galileo telescope.

Site investigation and laboratory testing have shown that the ground subsurface consists of alternating layers of basalt blocks and very dense tuff. The telescope pier shall be placed on a circular plate foundation, directly connected with the first basalt layer, at a relatively shallow depth below surface (~2.5 m). Measurements of background and induced vibrations reveal that their levels in the vertical, horizontal N-S and horizontal E-W directions are very nearly of the same strength and very low: less than 5 × 10^{-6} g, in the frequency range 0.063 to 10 Hz, and less than 6 × 10^{-6} g in the range 0.063 to 100 Hz.

The TNG will be housed in a building which has been designed retaining several solutions of the ESO NTT, but with significant differences imposed both by the different environment and by the different scientific and operational requirements. The rotating part is very similar: sandwich panels, covered with metallic surfaces on both sides, flame resistant and with a low heat transmission coefficient, fill a steel skeleton of octagonal shape which rotates over a bearing 9200 mm in diameter (Fig. 3).

However, the requirement to be able to exchange upper ends implied an increase of approximately 1 m in the height of the two slit shutters; the slope to the roof has also been augmented with respect to NTT, to improve impermeability in a more severe winter climate.

The central pillar is a hollow reinforced concrete cylinder 0.610 m high (~5 m more than NTT), inside which a darkroom has been obtained for spectroscopic purposes. The light will reach this central room via optical fibers from the Nasmyth foci. The considerable increase in height, due to the different ground conditions that suggested to have the elevation axis higher then the NTT for smaller ground turbulence, and the higher horizon from the mountain sloping to the South, implies also that the pier, and the central ball bearing on which the building rotates, must be increased in diameter.

The ground level will be used for equipment storage, to park the truck for aluminizing M1, and to deposit M2 and M3 units. A southward asphalted steel bridge connects the observing floor level to the existing road. The bridge will be used during construction to bring into the floor the large pieces, and also subsequently to remove and reinstall M1 for its alumination (foreseen in the UK facility at the WHT).

Air flow in the telescope area will be controlled, as in NTT, by five tiltable flaps installed in the rear wall of the dome, with a mobile windscreen in front. Flap operation is monitored by an encoder, and the control electronics will allow any opening angle between 0 and 90 degrees. A rear door, in two sliding sections, connects the fixed bridge directly to the observing floor and can also be used, in conjunction with the above mentioned flaps, to control ventilation of the telescope area during observations.

Electric power, data link and compressed air are distributed in the rotating building by a cable wrap located in the base ring. This will allow installation of additional lines (e.g., optical fibers) with a relative rotation of ±270° between the fixed and mobile part.

One of the most stringent scientific requirements of the TNG is optimal imaging. To this end, great care has been taken in controlling the temperature and the air flow of the several ambients. The air conditioning system must maintain the temperature of all telescope surfaces and of both Nasmyth rooms very close to that expected during night-time. Sixteen temperature sensors monitor the various zones under the control of a central supervision system located in the annex building.

Four air handling units will be placed on the observing floor (Fig. 4): they will suck air from the top through drilled ducts with a calibration flap closure, then treat and distribute it into the false floor, mixing it with the primary one coming directly from the outside. Low-momentum diffusers will return the air from the ceiling floor to the telescope and Nasmyth rooms. This philosophy keeps the necessary overpressure and dehumidification, ensuring a stable temperature gradient, with cooler air in the lower parts, thus preventing any arising of air by convection.

The glycol-producing units (chillers) will be placed about 100 m from the building, on the S-W side. The concept is to track the external temperature with the temperature of the liquid, whose minimum operating temperature will be −8°C. The chilled water/glycol in/out lines are carried to the rotating parts by a rotating joint located under the fork base of the telescope.

The service building, located on the South side of the dome in order to be downwind, is a one-floor structure as large as the rotating building and directly connected to it. It contains the control room, the auxiliary power generator, electric equipment, electronics and optical laboratories, workshop, technical office, kitchen etc. The roof is covered with material extracted from the ground in order to minimize thermal exchanges and turbulence.

Therefore, the major difference with the NTT services is that the astronomer control room has been moved away from the rotating part, and located in the annex building.
From the annex building, the dome can be reached either via an elevator or through stairs.

6. Status of the Project

Construction of the TNG is well in progress; according to present plans the first light should be obtained in the second half of 1995. All the main contracts have already been awarded, except those connected with the dome and civil works, and with the rotator/adaptor. Namely:
Zeiss (Germany) for the 3 figured mirrors M1, M2, M3; a Consortium of Ansaldo Componenti, CRIV and INNSE (Italy) for telescope structure, azimuth rotation unit, M1 cell, and overall integration of all components; Macit (Italy) for M2 and M3 support structure; Softeam (Italy) for M1 and M2 actuators control; Hewlett-Packard (Italy) for the workstations; Interay (The Netherlands) for VME real time operating systems and Ethernet communication protocols; Heidenhain (Germany) for the encoders for the telescope axes and M3 movement; Sierracin (USA) for the azimuth, elevation, M3 rotation, rotator/adaptor motors; Carl Bro (Denmark) for soil investigations; Laserpoint (Italy) for ANTARES; Astromed (UK) for the ANTARES CCD camera.

The Project Office, located at the Astronomical Observatory of Padova, uses as consultants the following firms:
Consorzio Padova Ricerche for management and advanced technology support; ADS Italia for the design and control of the mechanical structure and movements; Zollet Ingegneria for the design of the civil works and of the rotating building; Studio Ingegneria Strada & Associati for thermal controls; ENG.ECO. for the electric plant.

Details about the VME system and controls have been given in C.Bonoli et al. (A distributed VME telescope control system for remote operations, Tucson, Apr. 1992); the workstation subsystem is described in M.Fucillo et al. (The Galileo Project workstation software system and user interface, ESO, Apr. 1992); a first plan for instrumentation has been expounded in the Report by F.Fusi-Pecci and G.Stirpe (TNG Instrument Plan: a progress report, March 1992) Technical Reports and a Newsletter are regularly issued.

It is our greatest pleasure to acknowledge here the continued support of the ESO personnel, in particular M.Tacchini, R.Wilson, F.Franza and L.Neuhe, and the kind assistance of the Instituto Astrofisico Canario, the Royal Greenwich Observatory and the Nordic Optical Telescope.
Figure 2: The structure of the TNG. Two Nasmyth foci will be immediately available. Other focal stations could be added later.
PHOTOLYTICALLY STABLE BLEACHED SILVER HALIDE HOLOGRAMS FOR ARCHIVAL STORAGE

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ABSTRACT
Bleached silver halide emulsions are the most popular holographic recording materials, due to their high exposure sensitivity, broad spectral response, easy processing and relatively good optical properties of the final holograms. Their disadvantages are poor stability to environmental radiation and relatively low signal to noise ratio. We have developed new bleach formulations, containing bromine with ammonium dichromate or ferric sulfate to overcome these disadvantages. In these formulations, bromine is either chemically synthesized in situ in the bleach or added and dissolved in it. Using commercial silver halide emulsions (Agfa BE56), holographic transmission and reflection gratings recorded and processed in these bleaches had relative high diffraction efficiencies (≥ 60%, absolute) and exhibited extremely high photolytic stability to print-out silver formation. This good stability, which was found to be due to bromine adsorption in the emulsion, is already reached in the bleaching step during processing, thereby obviating the necessity for subsequent unpleasant and complicating desensitization treatments. We shall discuss the influences of the developer and bleaching formulations on the dynamic holographic response in terms of refractive index modulation changes.

I. Introduction
Bleached silver halide (AgHal) emulsions are the most popular holographic recording materials, due to their high exposure sensitivity, broad spectral recording response, easy processing and relatively good optical properties of the final holograms. Furthermore, these emulsions are commercially available and have long shelf lives. In these emulsions, amplitude holograms of very low diffraction efficiencies (DE) are obtained during the initial chemical processing step. By a subsequent oxidation of the recorded silver patterns with appropriate bleaching solutions, the amplitude holograms are converted to phase holograms having high DEs. In these, the refractive index modulated phase gratings consist of a periodic variation in the number of AgHal microcrystals imbedded in gelatin. The bleached holograms, unfortunately, have two major disadvantages. The modulating AgHal particles may, by recrystallization in the bleach bath, grow in size, leading to increased scattering during read-out. Also, the grains retain some light sensitivity and may darken photolytically by exposure to read-out or environmental radiation.

In this paper, we present new, ammonium dichromate and ferric sulfate based...