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The Telescopio Nazionale Galileo

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Abstract. This report briefly summarizes the status of the ⊘ 3.58m Telescopio Nazionale Galileo (TNG) and provides statistical information on the downtimes, observing requests, costs and publications rate. It also presents a few scientific results which particularly highlight the virtually unique capabilities of some of its instruments. The overall picture is that of a competitive, efficient and cost-effective facility which is very much appreciated and used by the Italian and international astrophysical community.

Key words. Telescopes – Instrumentation

1. The TNG instruments at a glance

Five years ago, in the summer of 2000, the Telescopio Nazionale Galileo (TNG) was completed with all its baseline instruments which consist of two efficient and versatile multi-mode imager/spectrometers working at optical ("DOLORES") and infrared ("NICS") wavelengths, a high resolution optical spectrograph ("SARG"), a direct optical imager ("OIG") and an adaptive optics module ("AdOpt").

DOLORES acts as the workhorse for all those programs requiring fairly wide field and/or low-medium resolution spectroscopy. The performances of this instrument are in line with those of the numerous, high efficiency multi-mode facilities available on other 4m class telescopes.

SARG, the high resolution spectrometer, is a remarkably high-efficiency and high-stability instrument designed with the specific purpose of obtaining very accurate radial velocity measurements. At wavelengths longer than 4000 Å it is one of the best high resolution instruments presently available on 4m class telescopes.

OIG is optimized for high quality imaging and is the only optical imager which can take full advantage of the relatively frequent periods of good seeing when the PSF cannot be sampled by the much coarser scale and poorer image quality offered by DOLORES

NICS is one of the most efficient and versatile multi-mode near IR instruments operating worldwide. In low resolution spectroscopy it can directly compete with 10m-class facilities.

AdOpt is an optical bench permanently mounted on the Nasmyth-A derotator and can feed NICS or OIG. It is the only system worldwide employing a pyramid wavefront sensor and operating on night-time telescope dedicated to scientific observations. AdOpt has been extensively used to demonstrate, with great success, the technical viability of this system, but had so far limited scientific applications due to the difficulty to operate it. Nonetheless, a thorough upgrading of its control system is in progress and should soon allow routine observations also in service/queuing.

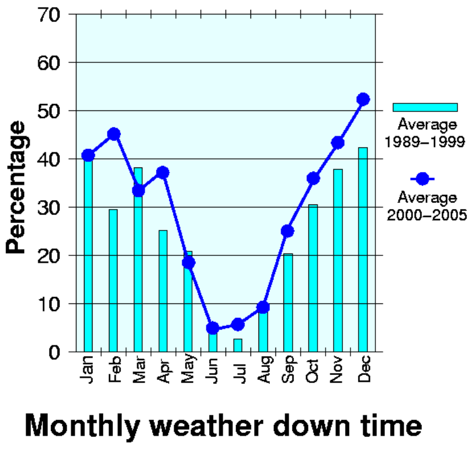

Fig. 1. Weather downtimes per month averaged over the last five years (dots+curve, based on TNG data) and pver the 1989-1999 period (based on data from ING).

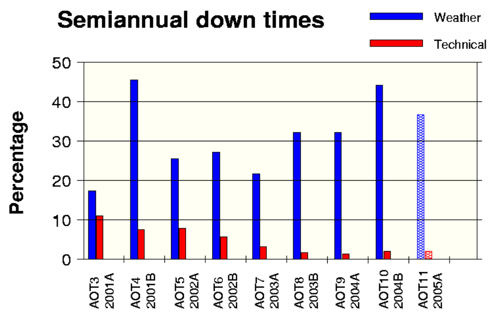

Fig. 2. Weather and technical down-times averaged over the last 9 observing periods. Each observing period covers a period of six months, the data for AOT11/05A are for 5 months (Feb-Jun 2005).

All the instruments, except AdOpt, were commissioned in a very short time and, since the beginning of 2001, all the system has been working on a routine basis offering to the Italian and international community one of the most complete and flexible combination of instrumentation worldwide.

2. Operations and budgeting

TNG is one of the few, if not the only, 4m-class telescope worldwide heavily employing service observations with flexible and queuing scheduling. The fraction of programs scheduled in service is close to 50% of the total night-time available. All the operations, from the assistance to the preparation of the observing blocks to the actual observations and extraction of the data from the archive, are handled by only 7 astronomers. The same staff astronomers are also responsible of the quality control of the data and of the development of the calibration plans. Such an heavy duty work results in a significant cost saving but, however, limits the development of scientific activities led by local astronomers. In other words, the prime aim and activity of TNG is to offer a service to the community.

In parallel to its routine astronomical work, TNG is also undergoing a thorough upgrade of a significant fraction of its hardware and software systems. The aim is to increase the reliability and efficiency of the system, following the prescriptions of the 2001 report of the *gruppo istruttorio per il TNG* led by R. Pallavicini. The work is performed by 13 technical staff members who also take care of the regular maintenance of the telescope and instruments. While much progress has already been achieved in terms reliability (the technical downtimes in the last two years are below 2%, see Fig. 2), a lot of work is still needed to achieve a higher efficiency. In particular, one needs to increase the speed of CCD control systems, parallelize the setup operations of the instruments and eliminate (automate) a large number of manual operations which are normally performed during an observing night. Thanks to the use of flexible scheduling, all the technical works are handled with virtually no impact on the scientific observations.

From the budgeting point of view, TNG is possibly the most cost-effective 4m-class telescope among European astronomical facilities. Its cost per night (about 7300 Euros, see Fig. 3) is much lower than competing telescopes at Mauna Kea or La Palma and virtually identical to that of ESO-NTT whose running costs, however, are mitigated by the fact that the same staff takes also care of the 3.6m and 2.2m of LaSilla. This result is particularly important if one considers that service observing with

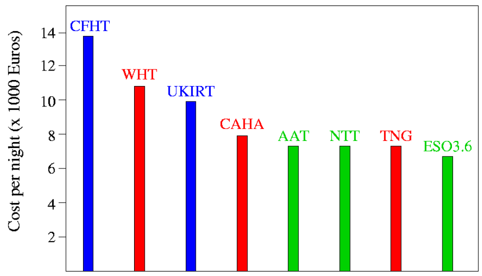

Fig. 3. Costs per night of 4m class telescopes participating into the OPTICON access program.

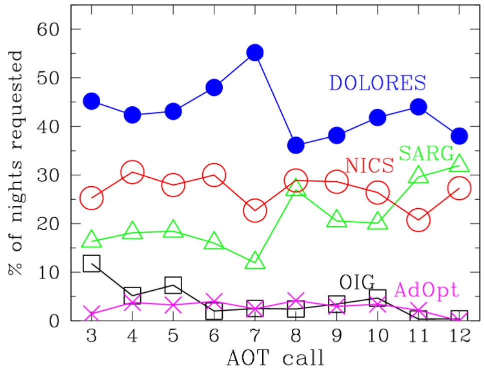

Fig. 5. Distribution of time requests to the TNG-TAC by instruments. The AOT calls are semiannual and span the 2001 (AOT3,4) to 2005 (AOT11,12) years.

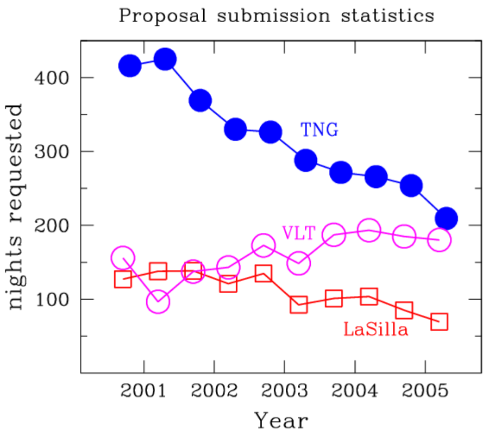

Fig. 4. Evolution of time requests in proposals to the TNG-TAC compared with the proposals submitted by Italian PI's to ESO.

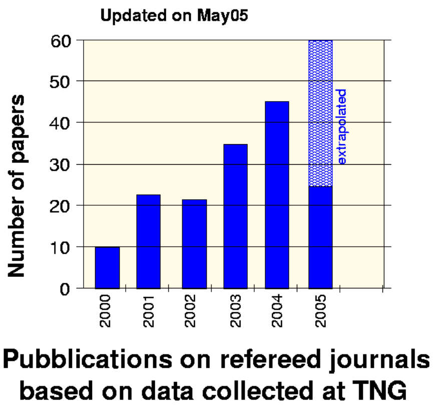

Fig. 6. Pubblications on refereed journals based on data collected at the Telescopio Nazionale Galileo.

queuing scheduling, normally considered as a very expensive activity, is performed at impressively high levels by TNG.

3. Downtimes

The monthly weather downtimes at TNG averaged over the last 5 years are similar to those recorded by the Isaac Newton Group (ING) group in the last decade (see Fig. 1). The results confirm that the site of La Palma is strongly seasonal, with extremely good conditions in summer but with a quite high fraction of useless nights in winter.

This has created quite some frustration to astronomers interested in extragalactic research - indeed a large fraction among those applying to TNG time - who usually point toward objects which are best visible between late autumn and early spring. Nonetheless, the intensive use of queuing observations has alleviated the problem and made it possible to complete most of the proposals to which the TNG time allocation committee has awarder the highest scientific merit.

The down-times by semester are displayed in Fig. 2. The time lost for bad weather is on average 30% but with quite large variations

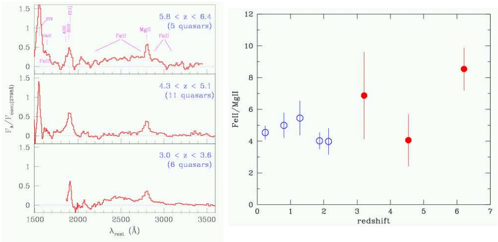

Fig. 7. Left: average, continuum subtracted NICS/TNG spectra of high-z quasars showing the FeII and other metal lines. Right: deduced Fe/Mg abundance ratio as a function of redshift, filled dots are solely based on NICS/TNG data.

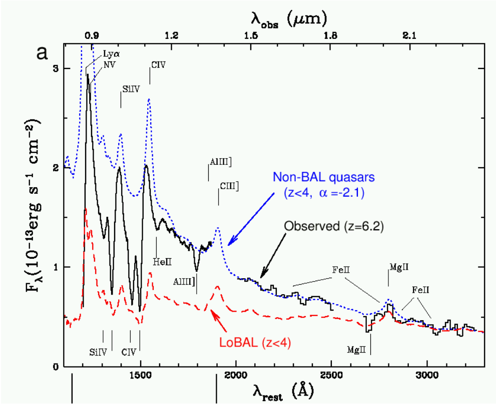

Fig. 8. NICS/TNG spectrum (black solid line) of one of the most distant object known in the universe (z=6.2). The dotted and dashed lines are the spectra of similar objects much closer to us. The red dashed line corresponds to dusty quasars, while the blue dotted line to dust free objects.

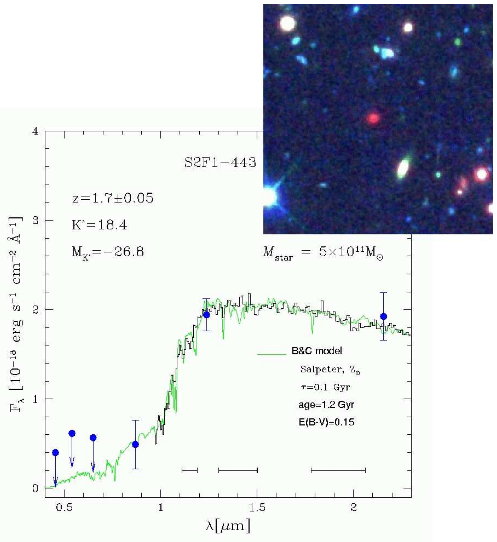

Fig. 9. False colour image (red=K, green=J, blue=I) and NICS-Amici spectrum of the extremely red object (ERO) at the center of the field. The data (black histogram) are remarkably similar to the spectrum of a giant elliptical galaxy at the record redshift of z=1.7 (green line).

among different observing periods caused by the succeeding between remarkably mild and stormy winters, such as those of 2000-2001 and 2001-2002.

The technical downtimes, defined as the scientific time loss due to the failure of the telescope and/or instrument system, show a definite trend from about 11% in early 2001 to below 2% in 2004 (see Fig. 2). This reflects the good results of the detailed maintenance work aimed at stabilizing the telescope and focal plane systems. The drop in 2003 is also related to the activation of the service mode with flexible scheduling which allows a much more efficient handling of the technical and scientific times.

4. Proposals

The statistics of time requests to the TNG-TAC are summarized in Figures 4. There a definite trend in the total time requested which has decreased by almost a factor of 2 between 2000 and 2005, and the over-subscription rate has consequently dropped from a factor of about 4 to 2. A similar, though less pronounced trend is also visible in the time requested by Italian astronomers to the ESO 3.6m and NTT telescopes at La Silla (red squares in Fig. 4), while the Italian requests for the ESO-VLT has increased and reached values close to those of TNG.

This is most probably a direct consequence of the stunning growth of new instruments offered by VLT during the period under consideration as well of the increasing difficulty of astronomers to "digest" the always increasing amount of data produced at the telescope.

In this respect ESO has the main advantage of providing already reduced data to the astronomer who, therefore, can save a lot of time by-passing the, sometimes painful, task of data reduction. A last effect could be also related to the weather downtimes at La Palma which have repeatedly frustrated the attempts of several groups to complete their investigations on objects which are best visible in winter.

The distribution of time requests by instruments is displayed in Fig. 5. The "classical" optical imager and low resolution spectrometer (DOLORES) is the most requested instrument, immediately followed by the multi-mode infrared instrument (NICS) and the high resolution optical spectrometer (SARG).

The direct CCD imager (OIG) attracts very little interest, possibly because its field of view (5' x 5') is much smaller than that available with DOLORES (9' x 9').

The very few requests for the adaptive optics module may reflect the difficulty of operating the system and achieving a reasonably uniform standard of data quality with just a few nights a year scheduled in visitor mode. Since the AdOpt instrument can only work in good seeing conditions, the only way to achieve scientifically useful results is to perform the observations in service/queuing mode. To achieve this aim the instrument is undergoing intensive refurbishment works aimed at creating a reliable and user-friendly system.

5. Publications statistics

The number of articles based on TNG data published on refereed journals has steadily increased in the last 5 years, and reached in 2005 the remarkable rate of 5 papers per month (see Fig. 6). The first, important step forward occurred in 2001, just one year after the first light of the 3 spectrometers (summer 2000), while the major increase started in 2003. This 2-3 years time-lag is similar to what occurred in other telescopes and reflects the typical time normally necessary by astronomer to properly analyze data coming from new instruments.

Remarkable is the anti-correlation between the publication rate, which has increased by a factor of ~3 from 2001, and the requests for observations which have decreased by a factor of ~2 over the same period (see Fig. 4).

6. Science highlights

This section does not pretend to select the "best" scientific results achieved using TNG data, a task which is indeed far beyond the aim of this report. Rather, it summarizes a few, recent publications which emphasize the quality of the data obtained at TNG relative to other works based on observations at other telescopes, including Keck, VLT and other 10m-class telescopes.

6.1. High redshift quasars

The TNG/NICS combination has produced the most complete data-base of low and medium resolution spectra of the farthest quasars (z>5) discovered by the SLOAN survey. These spectra, whose quality is comparable or even better than those obtained at 10m telescopes by competing groups, yielded important information on the physical and chemical conditions in the early (<1 Gyr) Universe and, consequently, constraints on the how the first generation of stars have formed and evolved in the first few hundred million of years after the big-bang. Below is a brief summary of the most important results, for more details see Maiolino et al. (2003, 2004a,b)

- The abundance of iron relative magnesium and other metals remain constant, or even increase, at z>5 (see Fig. 7). The production of such a large amount of iron requires a major episode of star formation occurring at redshifts z>9 in the host galaxies of these quasars. This starburst possibly corresponds to the violent birth of the very first generation of massive stars which rapidly synthesized, via thermo-nuclear reactions in their interiors, all the elements heavier than Helium – including the magnesium and iron observed in the quasars – and expelled them into the interstellar medium by exploding as supernovae at the end of their short (few million years) lives.

- Broad-absorption line quasars (BAL-QSO) are relatively rare in the local universe but become the most common form of quasars at z>5. The huge amount of outflowing gas, responsible for the absorption lines, indicates that a large-scale star formation event has formed the massive galaxy hosting the active nucleus at epochs much earlier than predicted by the popular CDM models.
- The continuum spectral shape of the high redshift BAL-QSO's is remarkably different than that observed in lower redshift (i.e. older) quasars (see Fig. 8). At long wavelengths (>1800 Å rest frame) they are remarkably similar to local dust-free free active nuclei, but show clear evidence of dust absorption at shorter wavelengths. This demonstrates that the very first generation of star-burst supernovae also produced a large amount of dust grains with optical and chemical properties very different than at present times. The formation of dust grains at such early epochs has fundamental implications for the subsequent evolution of the galaxies, since these grains strongly favored the formation of molecules, of low-mass stars and of their planetary systems.

6.2. Old and massive galaxies at z>1.5

Faint, spatially extended and very red obejcts (called EROS) are commonly found in optical/IR imaging surveys. Their nature is controversial. Their colors are compatible with relatively small and dusty star-burst galaxies, but also with giant galaxies with a dominant population of old stars at redshifts z=1-2. The latter interpretation implies that large scale star-bursts and massive galaxies have already formed at very early epochs (z>7), in strict contrast to what predicted by the popular CDM model which postulates that star formation starts on small scales and that large galaxies are formed at later time by the merging of smaller systems. Hence the importance of obtaining quantitative spectroscopic information of EROS. However, this is a very difficult task because of their low fluxes and red colors. Infrared spectroscopic study carried out at 10m-class telescopes failed to produce unambiguous results. The only quantitative measurements are based on optical (CCD) spectra, but these are limited to the least red objects.

A major step forward in this field was recently performed at TNG, thanks to the unique performances and capabilities of the NICS-Amici disperser. Using these spectra (see Fig. 9 for an example) Saracco et al. (2005) identified 10 among the most massive (>3 10^{11} $M_{\odot}$) and distant (z=1.2-1.7) field elliptical galaxies in the Universe. The presence of such giant evolved galaxies at these redshifts suggests that the assembly of massive spheroids has taken place at red-shifts z>7 thus supporting a high efficiency in the accretion of the stellar mass in massive halos in the early Universe. Moreover, one object is the most massive and distant early-type galaxy (z=1.7) discovered so far. In this galaxy new X-rays data from the XMM-Newton satellite unveiled the presence of a strongly obscured and high luminosity active galactic nucleus (AGN), thus corroborating the link between the Quasar activity and the formation of massive galaxies at very high redshifts.

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