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A. Ghedina, C. Barbieri, F. Bortoletto, S. di Serego Alighieri, E. Oliva, G. Ceppatelli, E. Molinari, E. Poretti, R. Ragazzoni, W. Boschin, "Celebrating 20 years of scientific and technical results with the INAF-TNG Telescope," Proc. SPIE 10704, Observatory Operations: Strategies, Processes, and Systems VII, 107041A (10 July 2018); doi: 10.1117/12.2312047

Event: SPIE Astronomical Telescopes + Instrumentation, 2018, Austin, Texas, United States

Celebrating 20 years of scientific and technical results with the INAF-TNG telescope

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ABSTRACT

June 9th, 2018 marks the 20^{th} anniversary of the first light of the INAF-Telescopio Nazionale Galileo. This paper is a resume of the main scientific and technical results obtained with the TNG, together with the history of the telescope, the instruments and the people who allowed for several successes and many lessons learned. We will point out what made the TNG a telescope which still can make competitive research in the large and extremely large size telescopes era.

Keywords: Astronomical Telescopes, Anniversary, TNG

1. STUDY, DESIGN AND CONSTRUCTION

In 1988 the Italian Council for Astronomical Research (C.R.A.) approved the idea to participate into the ESO-VLT project, in the Columbus (now LBT) telescope and in a national 4-m class telescope optimized for high-resolution[1]. The following year Cesare Barbieri was designated as Director of the Galileo Project[2]. With the input of the entire Italian astronomical and industrial community the main characteristics of the telescope were decided, choosing as a starting point the ESO NTT model, but implementing several upgrades:

- 3.58 meniscus mirror with AO, working in parallel with transputers;
- an exapod to support M2 and Tip Tilt capabilities for M3;
- Ritchey-Chrétien optical configuration with two Nasmyth Foci at F/11, with 80% of Encircled Energy (EE80) within 0.3 arcsec in passive mode and 0.15 arcsec in active mode;
- possibility of a prime focus and of a trapped F/6 focus. To allow this options the configuration of the spiders was changed to 60deg separation for easier removal, the building raised and a new crane added;
- new TCS and OCS;
- location sites to be chosen between Mt.Graham, La Palma and Mauna Kea.

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Observatory Operations: Strategies, Processes, and Systems VII, edited by Alison B. Peck, Robert L. Seaman, Chris R. Benn, Proc. of SPIE Vol. 10704, 107041A · © 2018 SPIE
CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2312047

In 1991 an agreement with UH could not be reached and the final site became La Palma, in an area of the mountain previously visited and impressive for its seeing quality. The mirrors (ZEISS) were completed and polished by 1992 and M1, once tested in its cell, showed a superb quality (well within the specifications) of 0.08 arcsec of EE80 in active mode. Also the Spherical aberration error was less than 500 nm, easily compensable with the AO system. Due to delays in obtaining the legal permission to construct, and huge devaluation of Italian Lira, the first contracts for excavation works were possible only in the late 1993. By the end of 1994 the Telescope had been already completed and moving (Ansaldo) and was then dismounted and shipped to La Palma. The first piece to be mounted was the azimuth box on the hydrostatic bearing (INNSE) even before the construction of the building (ZOLLET). A new bearing for the dome had to be installed (THK) due to bankruptcy of the original firm. The assembling of the dome begun in the second half of 1995 and the year after the telescope was installed. The official inauguration was in June 29th, 1996. However, many subsystems of the TNG still had to be installed, finished and tested (A/C, electric plant, Ethernet connections, meteorological tower, etc.). At the same time, and agreement between all the Italian astronomical observatories lead to the establishment of the C.N.A.A. (National Consortium for Astronomy and Astrophysics) lead by Marcello Rodonò, in order to manage and administrate the first national project[3] . With the first priority being to reach the full operation of the TNG, the CNAA appointed Sperello di Serego Alighieri Director of Operations and gave him instructions to constitute the sea level base in the Canary Islands[4,5] . The Galileo Galilei Center (CGG), initially foreseen in Tenerife within the IAC headquarters, was instead opened on La Palma, thanks to agreements that the Director made with the other two main institutions having telescopes at the Observatory, ING and NOT. Offices were then created, sharing the building with them. CNAA also begun to recruit the manpower for the following commissioning phase and for the future support of the Telescope and its instrumentations as permanent staff.

Figure 1. Two views of the Telescopio Nazionale Galileo from the outside and inside

2. THE COMMISSIONING, FIRST LIGHT AND DELIVERY TO THE ASTRONOMICAL COMMUNITY

At the end of 1997, next to the end of the construction phase (and with few months of overlap) Favio Bortoletto was given the direction of the commissioning phase[6] . The difficult task to setup and fine tune the whole telescope, services and subsystems was possible thanks to the formation of an enthusiastic and efficient commissioning group who integrated and fine tuned all the subsystems of the telescope, including the optics, the TCS and the instruments, one by one. In particular, the commissioning phase did not only mean the assembly and verification of the telescope and instruments, but also of the dome and services, among which we should point

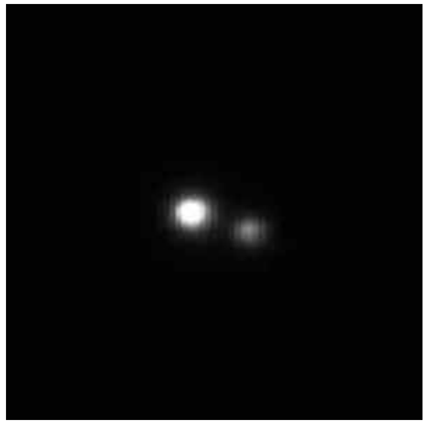

Figure 2. Image obtained at the TNG at first light. The double star Epsilon Lyrae 1, ϵ^1, taken in B band with the A&G camera. Separation is roughly 2.6 arcsec and seeing 0.8 arcsec.

out the hydrostatic bearing systems, the air conditioning, software and archives. As for the telescope the TCS and the AO were tested in deep and fine tuned to deliver top performances to the TNG. Some of the problems faced were due to the lack of pre-test and pre-installation in Italy of some subsystems, for example the optics of M2 and M3 inside their supports, the A&G optics inside the derotators or all the safety and interlock systems that could only be cabled and connected in situ.

In this way, with the coordinate effort of the commissioning group and after the right amount of struggling the first light could be finally achieved on the night of June 9^{th}, 1998, (see Fig.2) using an A&G camera mounted at the F/11 focus. Later phases of "first lights" were considered, as for the SH, the derotators, and finally during last months of 1998 for the first instruments OIG[7] (the Optical Imager Galileo) and Arnica[8] (Arcetri Near Infrared Camera, lended from Tirgo observatory for 2 years).

Table 1. TNG and Instruments first lights with main characteristics

Instrument	Date	Characteristics
TNG	June, 9^{th} 1998	F/11 Ritchey Chrétien with D=3.6m and AO
OIG	Dec, 10^{th} 1998	5x5 arcmin^2 FoV, U-Z and narrow band filters
ARNICA	Dec, 18^{th} 1998	1x1 arcmin^2 FoV, Y-K band
AdOpt	Dec, 18^{th} 1998	30 arcsec^2 FoV, PWFS, RT speckle camera
DOLORES	May, 20^{th} 2000	8.6x8.6 arcmin^2 FoV, R-500-6000,U-Z band, polarimetry
SARG	June, 9^{th} 2000	R=144000, 400-900nm
NICS	September, 17^{th} 2000	4.2x4.2 arcmin^2, R=50-1200, Y-K band, polarimetry
HARPS-N	March, 21^{st} 2012	R=115000, 380-700 nm, fiber fed
GIANO	July, 27^{th} 2012	R= 50000, Y-K band, fiber fed
GIANO-B	Oct, 27^{th} 2016	R= 50000, Y-K band, optical relay
GIARPS	March, 14^{th} 2017	simultaneous HARPS-N and GIANO-B

After the first light of the instruments few months were obviously dedicated to setup and tune the systems in order to make them really integrated into the observing control system and usable by the astronomers.

Thus during 1999 astronomical observations, on a best effort basis, begun for the Italian astronomical community in collaboration with the newly recruited staff of support astronomers base at the CGG. Most of the time was dedicated to collect feedback from the users and to debugging the user interfaces, adjust the configuration of the instruments to be more user friendly, minimize overheads and human effort, improve the precision of pointing, the smoothness of tracking and the correction of Active Optics[9] . Table 1 reports the date of first light of the instruments at the TNG.

The naming of the new TNG director Ernesto Oliva at the beginning of year 2000 can be considered as the end of the commissioning phase and the beginning of routinely scientific observations at the Telescope. The 4 main instruments always mounted at the Nasmyth Foci (OIG[7] , NICS[10] , Dolores[11] and SARG[12]), as originally foreseen in the design configuration of the TNG[13] , allowed for easy and fast change of configuration and versatile observing modes, with minimal overheads. Even the Adaptive Optics module(AdOpt@TNG[14] could be easily introduced in front of NICS to give diffraction limited images.

The first formal call for observing time (AOT) was issued for the beginning of the year 2000 and with it there was the creation of the first official Time Allocation Committee(TAC) chaired by T. Maccacaro. This TAC had been preceded by an experimental group, created in 1997 under the supervision of F. F. Pecci, with the aim to define the guidelines for the following TAC meetings. AOTs were progressively numbered starting with the AOT1 of January 2000, and each one lasting usually 6 months (the first few were of 4 months, sometimes we made AOTs of 7 months). In parallel with the Italian TAC there is also a Spanish CAT (Comité de Alocación de Tiempo) who is in charge to assign 20% of the observing time to the Spanish community. In fact following the rules for the observatory in La Palma the price to pay in order to build a telescope on Spanish territory is to give 20% of the observing night time to Spain. A further 5% of observing time is given to the International community.

We have just closed the call for AOT38 and the original configuration of instruments is no longer available. OIG was the the first instrument to be decomissioned and in 2008 also the AdOpt@TNG was dismounted. In 2012, with Emilio Molinari being the director, two new instruments begun observations at the TNG and soon produced high quality data thanks to their unique capabilities: HARPS-N[15] and the fiber fed GIANO[16] , two high resolution spectrographs respectively in the visibile and Near infrared bands. Later SARG was decomissioned by the end of 2012, being superseded by HARPS-N, and its removal allowed to translate GIANO to the Nasmyth B were, thanks to fundings from the Italian Premiale WOW, a new preslit unit was built with an optical relay feed. The smart move was to have the two spectrographs (HARPS-N and GIANO) much closer in order to be able to use them together in the GIARPS configuration[17] . In this observing mode a dichroic splits the visible and infrared lights between the two instruments and it is possible to take the simultaneous spectrum of an object from 380nm to 2450nm. Since 2017 this is a worldwide unique capability exclusive of the TNG, and in particular for exoplanets search, it allows to know and disentangle if the Doppler shift observed on RV is due to Stellar activity or to Keplerian effect. Of the first generation of instruments Dolores and NICS still maintain their positions thanks to their versatility and thanks to the interest of the Italian astronomical community in the high level research that still can be performed with them.

3. TECHNICAL ISSUES AND IMPROVEMENTS

Even if after the commissioning the TNG was already performing as expected and producing top level science, nonetheless several issues (mainly technical) had to be faced during the following years in order to keep the telescope and its research at competitive levels.

It can be seen in Fig.3 how the technical downtime became negligible after few years of system tuning. However, when the need of maintenance and improvement for the telescope and subsystems extended beyond the regular expected tasks, instead of going through a Big Bang has it happened for NTT, observations never stopped. Refurbishments, maintenance and upgrades were scheduled in order to have a minimum impact on regular observations. This policy is still used nowadays and a percentage of the observing nights is reserved as technical time to allow for tests of the changes introduced during the day. It is often necessary to connect the new parts during the morning, perform the necessary tests and switch back to the original configuration before the beginning of night observations. Even though the night operations are granted, the drawback is a huge waste of time and human effort before being able to definitively make the jump to the improved system.
During these 20 years there have naturally been issues with almost any part of the telescope, starting with

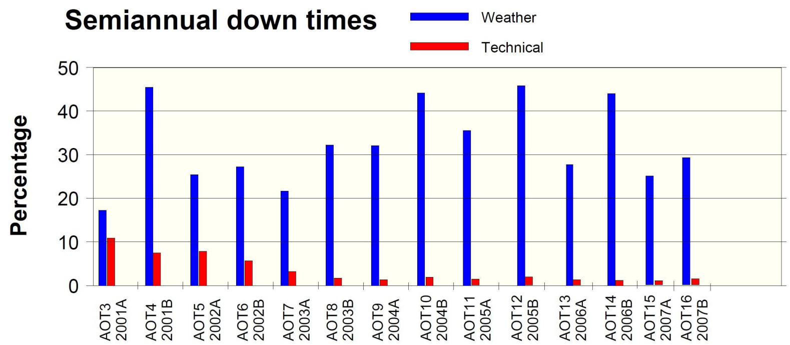

Figure 3. Initial semiannual downtime at TNG due to weather and technical issues[18]

the aluminum cover of the dome, the hydrostatic bearing (1998), and then the bearings of the dome (2003), of both derotators (2010) and of M3 (2011). Due to obsolescence and end of life several control systems had to be changed, in the control electronics part or in the devices providing the signal to their controls. The first systems to need a refurbishment were the ones based on transputers like CCD control systems and the active optics (2004-2006), then the analogical tachimetric of the motors (2006), the control systems for the A&G inside the derotators and then the guiding cameras (2007), the controls systems of NICS and Dolores (2008), the 4 glass encoders of the main axes (2014-2016). Also auxiliary services of the telescope had to be refurbished like the UPS (2008), a new DIMM (2010), or the construction of a new roof on the annex building (2015); the chillers and fans for the cooling (2014) and now the whole glycol pipes system (2017). Finally we are changing the whole TCS of the telescope[19] (2010-now): originally based on distributed VMEs with the GATE environment[20] and HP workstations for the high level software the system is slowly substituted with commercial drivers, LabView on CompactRio systems for the TCS[21,22] and with a new OCS, based on http protocols and web interfaces that allows for more automatism and data exchange between TCS and instruments[23] . Despite the need to repair and modernize most of the subsystems of the Telescope the observations have never been interrupted for long times. Even the aluminising of the main mirrors, a task requiring between 3 and 4 weeks of intense operations with the telescope closed to observations, and initially foreseen every 3 years, has been much less frequent thanks to the periodical washing of the mirrors (a normal 6 hour operation). In these 20 years the mirrors have been aluminised only 4 times (1999, 2002, 2006 and 2011), while keeping the reflectivity of each mirror always above 87%.
It could seem that nobody thought that the TNG could live so long and still be among the best 4-m class telescopes after 20 years, but most of the parts and instruments were clearly not built thinking throughly about regular maintenance, about aging of electronics and mechanics, or software development and dismissing of old versions. This is also due to the fact that in the quest for the highest performances many parts had obviously to be customized instead of bought COTS, so often no spare parts were available and a lot of back engineering had to be done when trying to adapt new technology and software to old subsystems.

We should thus point out two lessons learned from the experience with the TNG: the first one is that all of the subsystems should be tested and verified as much as possible during pre-assembly and integration, when it is still easy to access and modify any part. This is an important step, time consuming, that can delay the final AIT, but will relax the on site integration phase, where usually there are not the same resources as in home. The second lesson is again a sort of a compromise that must be taken when deciding which parts to install, if custom systems or commercial ones. The gain in performances and peak efficiency of a custom made part is sometimes not easily attainable because it is more delicate, needs tuning, needs more effort to give top performances while the commercial one has less performances, but it is usually cheaper, robust and reliable and at the end is always working, with plenty of spare parts if needed.

On the other positive side, in several occasions the TNG has been chosen as a test-bench for new technologies and instruments which have been successfully applied and which allowed to improve its competitiveness with respect to even bigger telescopes.

It is for example to be remembered that the now ubiquitous pyramid wavefront sensor (PWFS[24]) for adaptive optics it was first installed in AdOpt@TNG and it successfully closed the loop on a natural guide star in the year 1999. The ingenuity of the PWFS immediately showed its capabilities and efficiency to the whole astronomical community and now is widely used as WFS for adaptive optics systems worldwide.

TNG has also been the first telescope in the norther hemisphere to use Volume Phase Holographic grisms[25] into its instrumentation. To improve efficiency and resolution of Dolores the gOlem laboratory produced in 2001 a set of custom VPH with 40% better transmissivity and higher resolving power, much better than the originally installed traditional grisms.

Another remarkable and smart solution has been the introduction of an Amici[26] prism inside the NICS spectrograph. Its low resolution ($R \sim 50$) is compensated with an extremely high throughput which allows for detection of broad features on extremely faint targets like distant quasars or TNOs. Faint glimpses of light that are not anymore exclusively detected with 10-m class telescopes.

Other interesting add-ons to the instrumentations were the Real Time Speckle facility[27], the Geco wedge to compensate for mechanical flexures on Dolores[28], the polarimetric modes for Dolores (PAOLO)[29] and for HARPS-N (HANPO)[30].

The installation of HARPS-N[15] with smart improvements with respect to HARPS as the octagonal fiber and the optical scrambler, the improved coating on the optics, or the tip/tilt in the Front End Unit made it the most efficient spectrograph for extra-solar planet search.

TNG also accepted with great enthusiasm the opportunity to host the Green Astro Comb, a Laser Frequency Comb from the Stanford Center for Astrophysics, to be used as an absolute calibrator for HARPS-N[31].

4. SCIENCE AT THE TNG

Soon after the first light of each instrument the number and production rate of paper based on data collected at the TNG rapidly approached that of other top class telescopes.

From Fig. 4 it can be seen that the most productive instrument has been Dolores until last year. The optimum trend that brought to nearly 70 papers in 2013 shows a clear decrease in paper production for last year 2017. This can be explained due to the preference to long term programs devoted to exoplanet search which intrinsically need more time before producing papers. The study and research of GRB or SNe have throughly taken advantage of the possibility to easy switch between instruments. The observation made on a target of Opportunity policy (ToO) allowed for fast follow up of these serendipitous events during regular observations. These and other type of reasearch that would use the imagers and low resolution spctrogrpahs have now much less assigned hours and so less paper are produced with Dolores and NICS. There have been few years in which the queuing observing mode had been offered. During queuing observing the quality of data increases but at the same time as the effort to obtain such data and the time to complete the scheduled programs.

4.1 Scientific Highlights

We detail hereafter few of the most important scientific discoveries obtained with data taken at the TNG, to show the versatility and competitiveness that the TNG has shown during these years.

4.1.1 NICS Obtains the first infrared spectra of trans-neptunian objects ever done with a 4m class telescope

The first TNOs infrared spectra ever obtained with a 4 m class telescope were observed with NICS in the year 2000. Complete near-infrared (0.9-2.4 microns) spectral observations of trans-neptunian objects (TNOs) 2000 WR106 (actually named 2000 VARUNA) and 2000 EB173 (now named 38628 Huya) were done using the Amici prism disperser mounted on NICS. The two objects had $J = 18.2 - 18.5$ mag when observed, but nonetheless their spectra could be captured thanks to the low-dispersion - high throughput spectroscopic mode of the Amici prism.
Both spectra correspond to very red objects. The spectrum of 2000 WR106 has quite deep water ice absorption features at 1.5 and 2.0 microns.

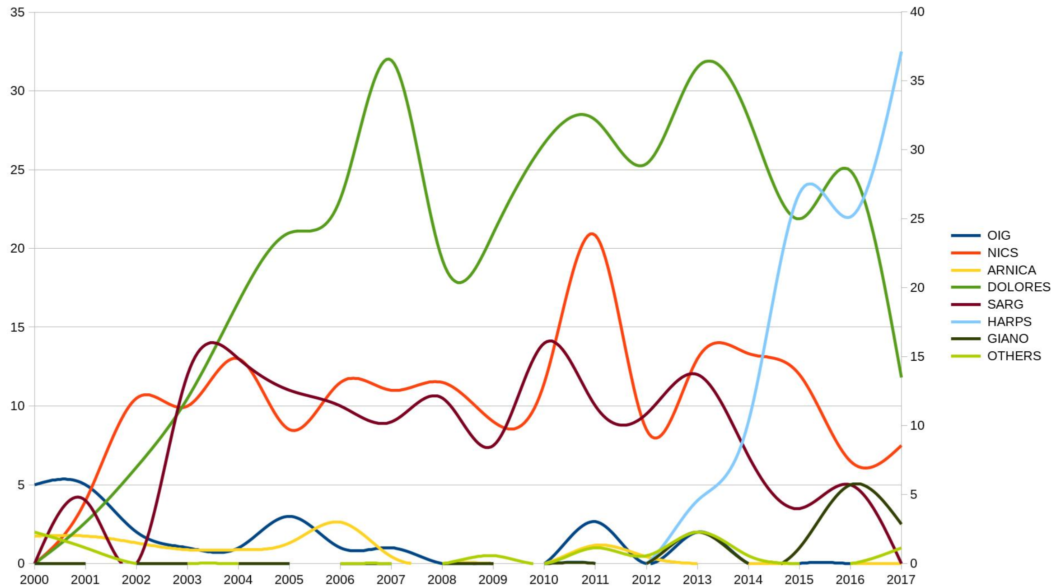

Figure 4. Number of refereed papers per instrument and year up to 2017. The "Others" group includes the Speckle Camera, SiFap, DIMM, AdOpt and the A&G Camera

TNOs are the most pristine objects of the solar system and probably contain some of the least modified materials remaining from the protosolar nebula. The study of the physical properties and evolution of their surface is very important from a cosmogonical point of view[32].

4.1.2 NICS data demonstrate that dust at high redshifts originates from Supernovae

Interstellar dust is known to play a crucial role in the evolution of the Universe. In fact, it assists the formation of molecules, triggers the formation of the first low-mass stars, absorbs stellar UV-optical lights and re-emits it at infrared wavelengths. NICS observations of a quasar at $z \sim 6.2$ shed new light on the origin of dust at high redshifts.
Previously, dust was thought to be produced predominantly in the envelope of evolved low-mass stars. Now, the dust extinction curve of the quasar obtained with NICS data suggests a different origin, with supernovae providing the most efficient dust formation environment in the early universe[33].

4.1.3 SARG spectra play a key role in the discovery of naphtalene in the interstellar space

Spanish researchers have succeeded in identifying naphthalene, one of the most complex molecules yet discovered in the interstellar medium.
The naphthalene was discovered in a star formation region in the constellation Perseus, in the direction of the star Cernis 52. The spectral bands found in this constellation coincide with laboratory measurements of the naphthalene cation. Optical spectra taken with SARG at TNG in November 2006 provided the first evidence of the presence of the naphthalene. Subsequently, spectra obtained with other telescopes confirmed the results obtained with SARG.
The detection of naphtalene suggests that a large number of the key components in prebiotic terrestrial chemistry could have been present in the interstellar matter from which the Solar System was formed. In fact, when subjected to ultraviolet radiation and combined with water and ammonium (both abundant in the space between the stars), naphthalene reacts and is capable of producing a wide variety of aminoacids and naphthaloquinones, precursor molecules to vitamins.

All these molecules play a fundamental role in the development of life as we know it on Earth. In fact, naphthalene has been found in meteorites that continue to fall to the surface of Earth, and which fell with much greater intensity in epochs preceding the appearance of life[34].

4.1.4 NICS catches GRB 090423, the farthest GRB ever observed

Gamma-Ray Bursts are among the brightest explosions in the universe, and in a few seconds they release a tremendous amount of energy, with their light illuminating the path from the source towards us.
Although these events, as observed form Earth, are rather frequent, on April 23^{rd}, 2009 at 7:55:19 UT the Swift satellite detected one of these events that represented a scientific breakthrough: GRB 090423. The instrument NICS and its low-dispersion prism Amici were able to take a NIR spectroscopic measurement of the GRB afterglow, providing an astonish value for its redshift: $z \sim 8.1$!
This burst happened when the Universe was only about 4 per cent of its current age. Its properties are similar to those of GRBs observed at low/intermediate redshifts, suggesting that the mechanisms and progenitors that gave rise to this burst about 600,000,000years after the Big Bang are not markedly different from those producing GRBs in the late Universe[35].

4.1.5 HARPS-N characterizes the first exoplanet with Earth-like mass and density

So far, the astronomers have characterized more than 1000 exoplanets, but Kepler-78b is a special one. Kepler-78b is an extra solar planet orbiting a Sun-like star located in the constellation of Cygnus, some 400 light-years away from Earth.
It was first spotted by the Kepler satellite detecting the tiny variation of light in the host star caused by the passage of the planet in front of it. Shortly after the discovery the TNG, thanks to a very intense observational campaign during the spring-summer months of 2013 with HARPS-N, was able to measure the mass of this exoplanet[36].
Kepler-78b has a radius of only 1.17 times that of the Earth (from Kepler data), while the mass is 1.86 Earth masses. These numbers yield a density of 5.57 grams per cubic centimeter, and imply a composition of rock and iron, thus making Kepler-78b the most Earth-like exoplanet known so far. However, Kepler-78b has a very short orbital period of only 8.5 hours and therefore it orbits at a close distance from its host star. This means that the temperature on the surface of the planet should be somewhere between 3000 and 5000 degrees, effectively ruling out any possibility of life as we imagine it.

4.1.6 HARPS-N finds the first Megaearth

The planet hunter HARPS-N allowed astronomers of the Consortium Italy-USA-UK-Switzerland to find a planet showing a composition similar to our Earth but 17 times heavier.
The Kepler-10c planet was first discovered by NASA Kepler satellite, measuring its dimensions, which are 2.3 Earth diameters. But only thanks to continuous observations lasting 2 years using HARPS-N it was possible to determine its mass, yielding a density of a rocky planet like ours.
This was a surprising discovery, considering that theories do not foresee the possibility of the formation of such big rocky planets, which in our solar system occurs in the form of iced Neptunes. This fact widens the possibility to find planets in habitable zones.
Every 45 days Kepler-10c orbits its solar type star which is a remarkably old star: 11 billions years compared with our younger system, aged 4.5 billions years[37].

4.1.7 HARPS-N contributes to the discovery of the first multi-planet system in an open cluster

Open cluster stars share the same age and metallicity and, in general, their age and mass can be estimated with higher precision than for field stars. For this reason, Open Clusters are considered an important laboratory to study the relation between the physical properties of the planets and those of their host stars, and the evolution

of planetary systems. However, only a handful of planets have been discovered around Open Cluster main-sequence stars so far, all of them in single-planet systems. For this reason the GAPS group (Global Architecture of Planetary Systems) started an observational campaign to search for and characterize planets in Open Cluster. They monitored the Praesepe member Pr 0211 to improve the knowledge of the eccentricity of the Hot-Jupiter already known to orbit this star and search for additional intermediate-mass planets. An eccentric orbit for the Hot Jupiter would support a planet-planet scattering process rather than a disk-driven migration after its formation. From 2012 to 2015, the GAPS team collected 70 radial velocity measurements with HARPS-N and 36 with TRES (Tillinghast Reflector Echelle Spectrograph on the 1.5-meter Tillinghast telescope, Arizona) of Pr 0211.
Simultaneous photometric observations were carried out with the robotic STELLA telescope (Tenerife, Canary Islands), in order to characterize the stellar activity. The results of this analysis allowed to discover a long-term trend in the radial velocity residuals due to the presence of a second, massive, outer planet and confirmed that Pr 0211b has a nearly circular orbit, with an improvement of a factor two with respect to the previous determination of its eccentricity. The study also allowed to estimate the mass for Pr 0211c as almost 8 times the Jupiter mass, a period P $>$ 3500 days and a very eccentric orbit. Pr 0211 is thus the first multi-planet system discovered around an Open Cluster star[38] .

4.1.8 Unique HARPS-N observations of the Venus cloud top winds

Ground based observations of Venus have been complemented by the space missions sent to study the planet, its atmosphere and winds, as the study of Venus climate has important implications on our understanding of Solar system in general, and Earth and its climate in particular.
In order to study the wind and upper atmosphere dynamics of Venus, a team lead by P. Machado has been developing observational strategies which use the spectra and the Doppler velocimetry techniques to map cloud top wind velocities. Such observations greatly benefit from the precision and stability of HARPS-N, the most precise spectrograph in the northern hemisphere[39] .

4.1.9 GIANO measures water in the atmosphere of an exoplanet: a first time for a 4m class telescope

The exoplanet HD 189733b is one of the most studied "hot Jupiters" to date. It is just slightly bigger than Jupiter, but it orbits over 180 times closer to its parent star, resulting in a roasting temperature of about 1,200 degrees. Every 2.2 days the planet transits the stellar disk, and a small fraction of the stellar light filters through its atmosphere, getting imprinted of its molecular constituents.
A team lead by M. Brogi (Assistant Professor at the University of Warwick, UK) has used GIANO at the TNG, in its initial fibre configuration, to detect water at high significance in the atmosphere of HD 189733b during transit. It is not the first time that this measurement was achieved, however previously only 8-10m class telescopes had succeeded. Thanks to the novel design of GIANO, specifically the large spectral coverage, these observations are now possible with 4-m class telescopes too[40] .

4.2 Scientific results with non conventional instrumentation

Apart from the main instruments installed at the focal stations the TNG has always been keen to host visiting instruments and make challenging tests based on novel ideas.

The first one we should remember is the experimental demonstration of feasibility of Multi Conjugate Adaptive Optics, that is by observing a set of bright stars (natural or artificial) around a dim target it is possible to apply tomographic techniques to reconstruct and correct the wavefront of light arriving from the target and in this way obtain its diffraction limited images. Using the A&G camera inside the derotator of the TNG it was shown for the first time that this technique was possible for closed loop adaptive optics system working in multiconjugate mode[41] .

There is also, outside of the dome of the TNG, another small dome hosting a low cost solar telescope (LCST). This instrument has been observing the Sun since July 2015 and feeding the scrambled light of our star to HARPS-N. Its purpose is to demonstrate that HARPS-N with a Laser Frequency Comb calibrator is able to detect the effect of an earth-like planet on a star, in this case of Venus[42] . The data collected are not enough yet to see the sign of Venus but the quest for this signal it is so interesting and challenging that an incredible group of astronomers has formed around this object and the consequences of observing the Sun a star. A similar telescope (HELIOS) is already working for HARPS in Chile and soon an infrared one (LOCNES, see 10700-170 in this conference) will be mounted close to LCST and feed GIANO-B.

Another remarkable result was obtained during the test of SiFAP[43] a high-temporal resolution optical photometer developed at the Department of Physics of the University of Rome La Sapienza and based on silicon photo-multipliers. SiFAPs was mechanically adapted for the TNG and during some tests it could observed for the first time ever optical pulsations from a transitional ms pulsar, PSR J1023+0038[44] .The instrument is so promising that a new improved version with polarimetry is being developed at the TNG and will soon start operations (see 10702-209 in this conference).

TNG also successfully collaborated to the Cosmic Bell Experiment made by a group from University of Wien under the direction of Dominik Rauch and the supervision of Anton Zeilinger. The color of photons, received simultaneously at the TNG and at the WHT (William Herschel Telescope) from two quasars lying in opposite directions, was the generator of arbitrariness in the choice of the measurement of polarization state in entangled photons which were fired at mid distance between the two observatories. In this way no local-realistic variables could alter the freedom-of-choice of the measurement settings. Their results showed with more than 9-sigma certainty that they violate Bell's inequality[45] .

Finally, both high resolution spectrographs installed at the TNG have given the opportunity to show the capabilities of laser frequency combs as astronomical calibrators, first on HARPS- N with the Green Astrocomb from the CfA,[31] then with the test of the TACCOR laser comb[46] and finally the test on GIANO-B of an infrared laser frequency comb from Univ. of Neuchatel based on micro-resonator.[47]

5. THE INVALUABLE STAFF

Some years after the creation of the CGG one great change for the staff has been the assignment by INAF to Guido Ceppatelli of the creation and administration of Fundación Galileo Galilei (FGG) in 2005, a non profit organization in charge of administrating the budget for the TNG. The staff which before had several different contracts was finally classified as full time employee of the FGG. Two years later in 2007 the offices of the FGG moved from the original site to a new bigger building with plenty of space, garages, laboratories and a class 1000 clean room. The new headquarters are closer to the Center for Astronomy in La Palma (CALP, where the GTC and IAC have their offices) and since few years we are sharing our resources with the NOT telescope who moved next to our offices.

From the commissioning to the actual status the staff of the TNG has always shown a generalized strong sense of loyalty, pride and identification in the Telescope. If not it would not be possible to explain the availability of anyone at any hour to resolve issues and eventually drive up the mountain to save the observing night or the telescope itself from possible damages. Up to now everybody has always performed its assigned tasks in a most enthusiastic and professional way, working alone or in group, coordinated with local or external people and always considering the Telescope as an opportunity to learn, grow and self-improve. But it is difficult to keep people motivated and involved when the budget is being reduced.

Furthermore the average age of the staff is shifting towards retirement values and it is time to introduce some generational turnover, recruiting younger forces, instruct new permanent staff and find other tasks for people who have been working here since the beginning.

6. FUTURE DEVELOPMENTS AND CONCLUSIONS

While the *Roque de los Muchachos* Observatory is wondering about which new telescopes and instruments will be available on the mountain in the next future, for the TNG neither there is a clear plan for third generation focal-plane instruments nor an institutional call for future developments. In previous years few projects for new instruments were proposed like prime focus correctors[48] or tunable filters[49] , but they had been dropped without any hope to be ever recovered. The options for the TNG to continue to be productive in the next future is based on the life of NICS and DOLORES (which have already been working for 2 decades) and, more effectively, on the new high-resolution spectrographs HARPS-N and GIANO-B. Indeed, both instruments (stand-alone or combined in the GIARPS mode) will have plenty of work for the follow-up of the targets that the new and foreseen satellites are expected to provide in a sort of uninterrupted chain. The spectrographs are still surveying *Kepler* and K2 stars, but GAIA and TESS candidates are already at the horizon. Later on, CHEOPS, PLATO, and ARIEL space missions will deeply attract the interest of the national and international teams using the TNG.

Moreover, some pioneeristic results are coming from SiFAP and for sure more with the improved version.

It is clear that the TNG is still competitive with the installed instruments and their versatility, mixed together with fast response capabilities and enthusiasm of the staff, but new projects and long-term planning (for the telescope and for the people) are needed to maintain the interest and motivation for 20 years further.

7. ACKNOWLEDGMENTS

All the above results could not be obtained without the effort and dedication of many people as staff or external companies which obviously cannot be named here and who contributed each one in its own way to bring the TNG where it is now.

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