The final commissioning phase of the AdOpt@TNG module.

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ABSTRACT

The AdOpt@TNG module is an adaptive optics facility permanently mounted at the Nasmyth focus of the 4m-class Telescopio Nazionale Galileo (TNG). Its integration on the telescope started in late November 1998 and first-light of the speckle and tip-tilt modes took place shortly after. Both modes have been offered to the astronomical community and turned out to provide performances close to the expectations. Double stars with separation below 0.1arcsec have been resolved by the speckle facility. Improvement of the Strehl ratio of a factor two and enhancement in the FWHM from 0.65arcsec to 0.35arcsec have been obtained on relatively faint reference stars. The high-speed low noise CCD, namely an 80x80 pixel read from the four corners, has been mounted and aligned with the Shack-Hartmann wavefront sensor. A Xinetics mirror with 96 actuators has been calibrated against the wavefront sensor with on-board alignment fibers. This has been done using a modal approach and using Singular Value Decomposition in order to get a reliable interaction matrix. Filtering can be modal too, using a default integrative filter coupled with a limited FIR-fashioned technique. Open loop measurements on the sky provide data to establish open loop transfer functions and realistic estimates of limiting magnitude. High–order wavefront correction loop has been succesfully tested on the sky. In this paper we give a description of the overall functionality of the module and of the procedure required to acquire targets to be used as reference in the correction. A brief overview of the very first astronomical results obtained so far on angular size and shape measurements of a few asteroids and sub-acrsec imaging of Planetary Nebulae and Herbig Haro objects is also given.

Keywords: 4m-class telescopes; adaptive optics module.

1. INTRODUCTION

In February 2, 1996 the Italian Council for Reasearch in Astronomy (CRA) decided to fund an adaptive optics module[1,2] for the Telescopio Nazionale Galileo[3,4], namely AdOpt@TNG (later, the cash flow came from CNAA) as one of the *first–light* instruments[5,6]. With the given funding profile no prime contractor was possible for such an instrument and the largest contract delivered in the framework of the development of the module accounted for less than 28% of the total expenditure profile. Most of the mechanics of the instrument have been manufactured at the mechanical workshop of the Asiago Astrophysical Observatory by the member of the group itself (...). While the optical design of the scientific channel[7,8] has been frozen shortly after, leading to a 1x1 arcmin Field of View with diffraction limited capability in the near infrared, the wavefront sensing channel has been re–arranged several times in order to accomodate for the mechanical constraints imposed mainly by the detectors used. Tip–tilt and high–order correction in fact, can follow in our module two completely separated loops. It is well known that variance of the tip-tilt term is large enough to make attractive solutions in which the correcting devices are specialized for tilt term only and high order terms only. In fact our instrument, like many others, is not an exception, and a dedicated tip-tilt mirror drives the first off–axis parabola. The pupil is reimaged on the deformable mirror: a 97 actuators Xinetics commercial mirror with limited capabilities for the tip-tilt term only (actually the pupil reimaged onto the DM leaves one rim of actuators around it, leaving some non–negligible wandering correction capability). Detection of tip–tilt is primarily referred to four Avalanche PhotoDiodes (APDs) coupled with a beam–dissector[9]. High order terms

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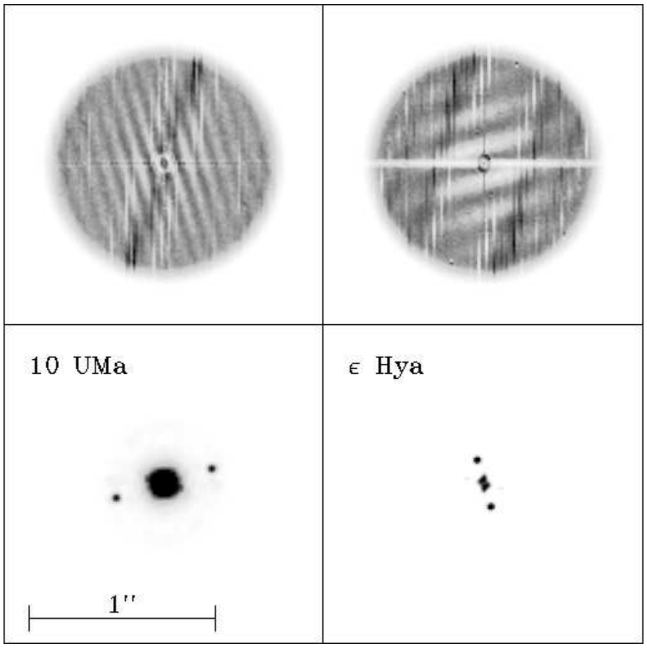

Figure 1. In this picture two examples of double stars detection by means of the speckle interferometry facility are given. In the two upper boxes the interferogram automatically provided by the real–time computing system is shown. This is really what the module delivers at the end of a few second exposure. Fringes are clearly seen, superimposed on a fixed pattern noise due to imperfections of the ICCD photocathode and to the interlace framing signal. After easy filtering of the latter and by inverse FFT (operations that take much less than a second of CPU time) the ACF of the original image is well recovered. Doublets as close as 0.09arcsec have been resolved in the engineering run of December 1998.

have to be measured with a fast, 80x80, 4 corner readings, CCD. The latter is optically coupled with a selectable Shack–Hartmann device whose sampling can be changed from 4x4 to 8x8 (actually we slightly changed the sampling to 5x5 and 9x9). Moreover a pyramidic wavefront sensing mode using an optical relay to transport the pupil of the telescope on the detector plane has been implemented[10,11,12]. In order to relax mechanical tolerances on the wavefront sensing system a reducing optics in front of the CCD reduces images coming from the wavefront sensing zone of a factor selectable during the alignment phase (now set to ≈ 10). This critical item turned out to be a relatively easy to align device.

2. FIRTH OF FIFTH

We previously realized two different speckle cameras respectively for the 122cm and 182cm telescopes in Asiago. We soon realized that most of the optomechanics required to build such a camera is already mounted in the AdOpt@TNG module.

Hence we decided to implement such a facility directly on board[13]. Initially our idea was to deploy the camera vertically with respect to the optical bench holding the adaptive optics train. Soon after the first preliminary drawings we realized that a normal on–bench implementation was possible (which is, of course, much easier from the mechanical point of view). The implementation of the data reduction has a different story. In the past experience we recorded on a videotape single specklegrams later reduced by a semi–automatic system. Data storage on videotape substantially hamper the quality and lower the signal to noise ratio. Moreover header recording and association to a specific tape portion is a somewhat complicated task if this has to be made in an automatic manner, and offered to the astronomical community with reasonable reliability.

We implemented a moderate parallel machine using the new (at the time of the development) PCI bus onto three industrial–grade Pentium–based computers[14]. Finally the system had the first light in December 1998. Occasionally

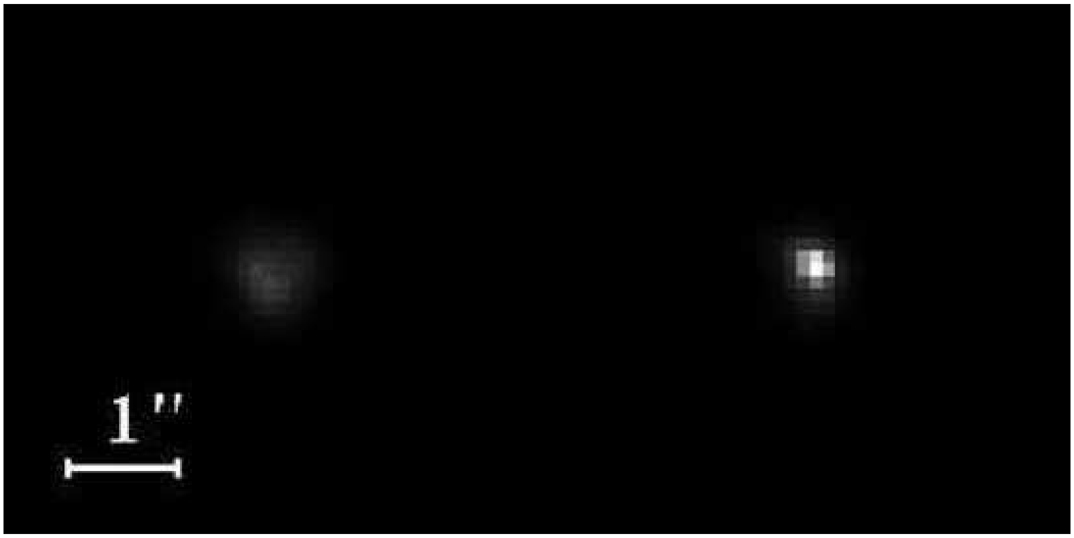

Figure 2. This $V \approx 13$ star observed under a seeing of ≈ 0.8 arcsec in the visible, exhibits a FWHM of 0.60 arcsec in the K' band (the infrared K band shortened to avoid the thermal emission from ground structures) in the left side and becomes only 0.35 arcsec FWHM when the tip–tilt loop is closed (in the right side). The Sthrel ratio enhancement approaches a factor of two.

one board has some minor faults, that are automatically tolerated and handled from the supervisioning system. Several double stars have been easily splitted into their components and the capability to measure the magnitude difference at various wavelength has been succesfully tested. Asteroids size determination has been employed too in two different run. Some hints on the shape of the observed objects can be drawn. Unless videotaping (an option always possible directly from the control room of the telescope) single frames are lost and only the accumulated power spectrum of the specklegrams is available at the end of any exposure.

Efficiency ranging from 25% to 35% (defined as the ratio of the collecting photons time to the total observing night time) have been reached so far, both during engineering and astronomical time offered to the astronomical community.

3. TUBULAR BELLS

The tip–tilt channel is based upon the development of a four APDs system initially developed at the Astrophysical Observatory of Arcetri[15]. The four APDs have been integrated in a stiff, optically coupled system able to dissect the image of a star into four quadrants and to fed the light into the 180μm sized APD sensitive areas.

This, as most of the module, has been designed based on the median seeing expected in the Roque site ranging between 0.6 and 0.7 arcsec.

Although seeing as fine as slightly worse than 0.5 arcsec has been recorded in several occasions at the focal plane of the TNG, our best seeing experienced during tip–tilt based observing run amount to roughly 0.8arcsec. In this occasion seeing in the K' band was ≈ 0.60 arcsec and several objects have been observed with sub–half–arcsec resolution. In a pair of occasion a FWHM below 0.40 arcsec has been recorded. Our current best result of 0.35 arcsec is shown in Figs.2 and 3. Such performances have been recorded during the whole observing night.

A different aspect to be adressed is the limiting magnitude of the tip–tilt channel. We achieved at the best $V \approx 13$ which is far of 2–3 magnitudes from the theoretical limit based upon real measurements. During that run enough data have been collected to estimate such a prediction. However a test with a relatively faint star is required. Moreover we currently use a 50%–50% beam splitter to fed light onto the acquisition ICCD used to place the star into the four quadrant sensor. It is unlikely that this option could be avoided in the near term unless *blind* pointing of the telescope could reach arcsec precision. Such a performance is currently only occasionally obtained when observing far from Zenith. Such a situation, however, could improve rapidly in the near future with better pointing models.

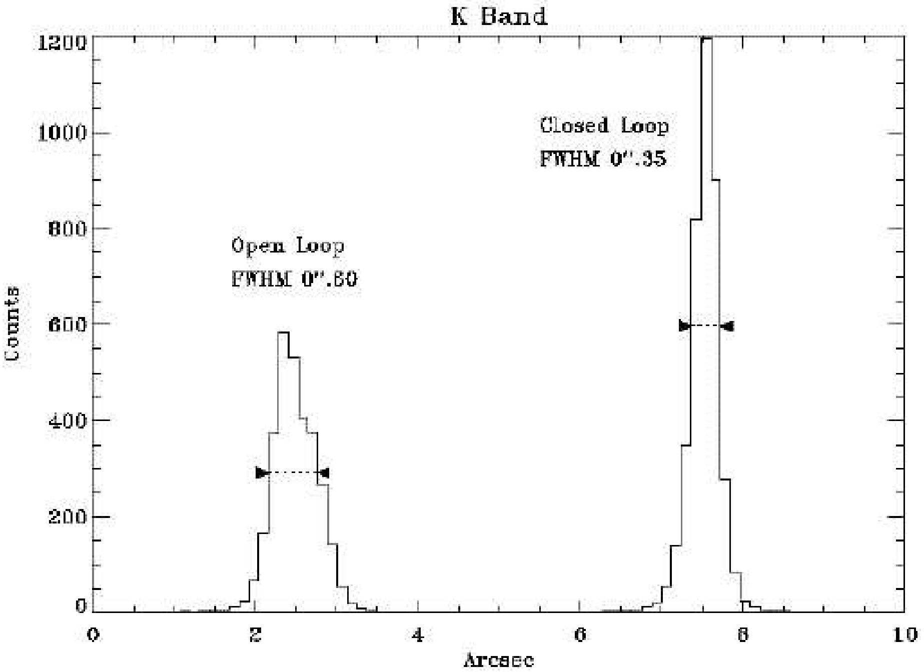

Figure 3. A profile of the stars in open– and closed–loop of the previous figure. Both Fig.2 and 3 are based upon raw data. Some pixel to pixel variation can be noted. Pixel size is ≈ 0.12 arcsec.

4. DU HAST

High-order correction is accomplished by a Xinetics 97 elements deformable mirror driven by a ThermoTreX wavefront computer. The latter gets information from a 80x80 EEV CCD read out by the four corners. We tested the CCD in the laboratory up to 400Hz leading to roughly 7 electron rms read–out noise. A relatively complex optomechanics is placed in front of the detector. After a field selector mirror located on the pupil of the telescope a lens re–form the F/32 beam collected from the beam–splitter. This is sent to a small optical table where three different wavefront sensing option have been built. Two channels hold Shack–Hartmann lenslet arrays for sampling of 4×4 and 8×8 over the telescope pupil. The third option include a re–imaging system to form an F/32 image of the observed reference on the pin of a small refractive pyramid. This can be moved in a plane perpendicular to the light propagation direction. Sinusoidal vibrations in such a plane are possible through a programmable electronics. We tested this device up to roughly 100Hz.

The three options have been designed in order to match the exit position of the focus of the two lenslet arrays and of the exit pupils for the pyramidic channel. In this way moving the small optical table will translate into the selection of a different wavefront sensing mode. Because this can be accomplished with a certain mechanical repeatibility, we placed, next, a reducing optics for a linear factor nearly ten, in order to strongly relax the mechanical tolerances on the wavefront sensor optomechanics.

Calibration is performed through a fiber–fed artificial source and introducing onto the DM several Zernike polynomials. Matrix inversion is performed through Singular Value Decomposition. Modal filtering, allowed by our WaveFront Computer, has been used in the first run just to decouple tip–tilt correction (performed through a simple

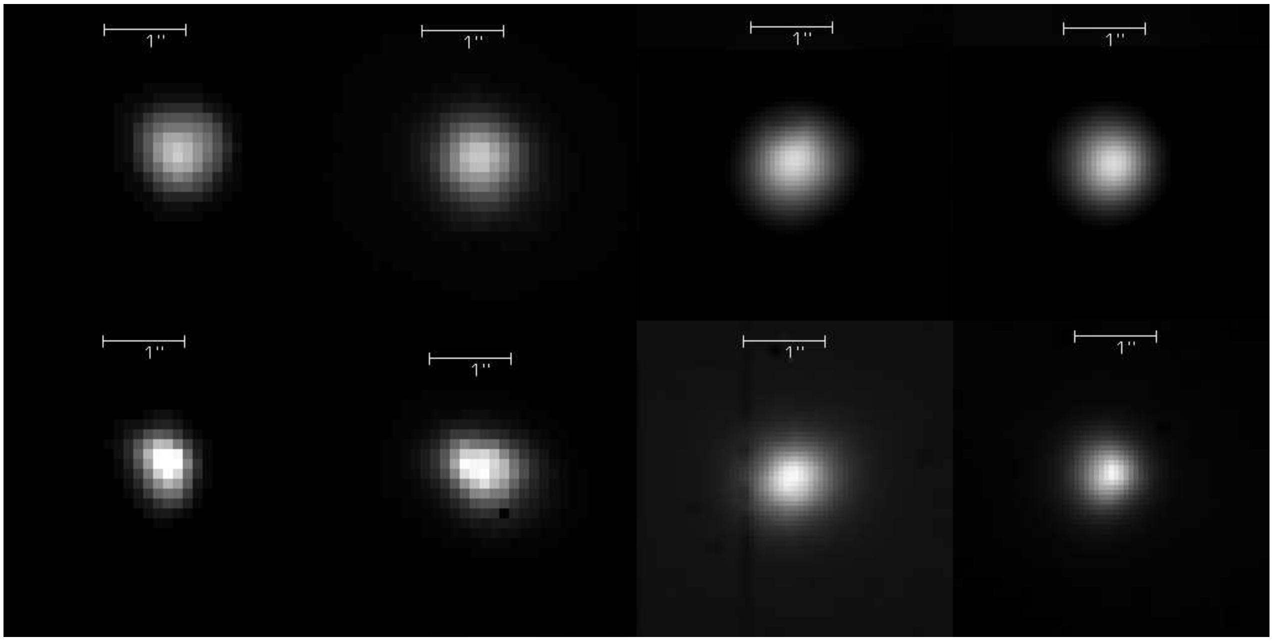

Figure 4. Four examples of astronomical frames in open loop (upper line) and closed loop (lower line): from left to right: NZ Ser in K' band; V1685 in the H band; NGC6826 in J band; IC2149 in H band. The first two objects are Herbigh–Haro, the second two are Planetary Nebulae.

integral filtering) and high–order correction (where a partial, 20%, integral component is superimposed to a fourth order Finite Impulse Response filter).

Actually we closed the high–order loop in the last night of a run plagued by bad weather conditions, namely November 29th, 1999, under a relatively poor (2.2 arcsec in V band) seeing. Improvement due to the only high–order (tip–tilt contribution has been here carefully removed) in the K' band produced 0.85 arcsec FWHM images starting from 1.10 arcsec FWHM, tip–tilt compensated images.

5. FIRST SCIENTIFIC RESULTS

In the framework of the instrument commissioning we acquired several frames with the purpose of retrieving some interesting scientific result. A few, Phase–A, observations have been somewhat succesfully carried out. Measurements of 3 out of 4 asteroids have been succesful[16,17] leading to volume estimates affected by an error of the order of 30%. Several stars have been splitted into couples. For one of them we measured the magnitude difference at five wavelength and we can state the spectral type of the secondary, confirming a single infrared observation made with the SOR adaptive optics[18] and in conflict with previous spectroscopic measurements[19,20]. Several observations of planetary nebulae and Herbig Haro objects have been carried out with sub–arcsec resolution (see Fig.4). Their usefulness to derive some firm conclusion to be submitted to peer–reviewed journal is under scrutiny. In the framework of isoplanatic measurements useful to assess the instrument capabilities we also performed the first on–sky realization of modal tomography[21,22]. An updated WEB page concerning the Adaptive Optics research carried out around the module described here is mantained at the URL: `www.pd.astro.it/adopt`.

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