Latest developments on the loop control system of AdOpt@TNG

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ABSTRACT

The Adaptive Optics System of the Galileo Telescope (AdOpt@TNG) is the only adaptive optics system mounted on a telescope which uses a pyramid wavefront sensor and it has already shown on sky its potentiality. Recently AdOpt@TNG has undergone deep changes at the level of its higher orders control system. The CCD and the Real Time Computer (RTC) have been substituted as a whole. Instead of the VME based RTC, due to its frequent breakdowns, a dual pentium processor PC with Real-Time-Linux has been chosen. The WFS CCD, that feeds the images to the RTC, was changed to an off–the–shelf camera system from SciMeasure with an EEV39 80×80 pixels as detector. While the APD based Tip/Tilt loop has shown the quality on the sky at the TNG site and the ability of TNG to take advantage of this quality, up to the diffraction limit, the High–Order system has been fully re-developed and the performance of the closed loop is under evaluation to offer the system with the best performance to the astronomical community.

Keywords: Adaptive Optics, Pyramid Wavefront Sensor, PIGS, TNG

1. INTRODUCTION

The original configuration of the AdOpt@TNG[1] control system has been deeply modified through time to meet the necessary conditions for normal operation. It has been shown that the Pyramid Wavefront Sensor[2] (PWS) performances on the sky[3] are equal or better than in a SH sensor. Furthermore the TNG is located in a top quality site, the Roque de Los Muchachos Observatory, in La Palma, as far as seeing conditions are concerned. The fact that the Tip/Tilt correction alone is often enough to reach the limit in angular resolution of the telescope in the near infrared (see Fig.1 as an example) forces us to look for the highest optimization of the high–order loop to fully exploit the site and the telescope.

Throughout 2003, a refurbishment of the optics and of the hardware and software side of the high–order loop has been done, taking the advantage of major works on the TNG. In fact the whole Nasmyth interface, which hosts the AdOpt@TNG bench, and the derotator system behind the interface, have been dismounted twice from the telescope's fork, in march and in august, in order to realign the encoders of the elevation axis and of the derotator. Furthermore the complete bearing of the TNG dome has been changed. The infrared camera and spectrograph (NICS), fed through the AdOpt@TNG module, has also been dismounted several times to correct movements of the wheels or to mount different masks on the slits wheel.

We sent the DM back to Xinetics to have it repolished, recoated and to adjust one of the actuators that didn't work. The other optics, two off–axis parabolae and other flat mirrors, were dismounted and received a new protected aluminum coating. We also sent the Proxitronic camera, used as acquisition camera in the wavefront sensor, to the company because it suffered of power breakdowns. Everything was mounted back again before june 2003 to do the tip/tilt observations and then dismounted for a second, definitive, alignment of the encoders.

While the Tip/Tilt system based on four EG&G APDs and the Xinetics Fast Steering Mirror has shown to work properly and in a robust way and is normally offered for scientific observations, the High–Order loop is not.

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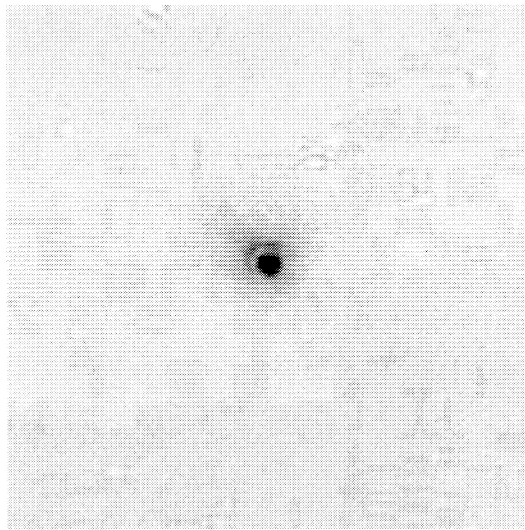

Figure 1. 30s, K' band image of a 7mag star (through a ND filter to avoid saturation). Tipt/Tilt correction only was applied, and the first diffraction ring is clearly visible, showing the high qualtity seeing conditions at the TNG. This image is of june 11^{th}, 2003

The previous VME based Real Time Computer (RTC) from Thermotrek, definetively had hardware or software problems that nobody could sort out, and that in random situations were responsible for making impossible to close the HO loop. We passed the whole loop control system under a PC–Linux real time machine with double processor. The RTC interacts directly with the new CCD camera controller and closes the loop. Another Linux PC is dedicated to be the User Work Station (UWS) substituting the previous SUN Sparc workstation and HP workstation.

2. THE CCD CAMERA

The first CCD camera used for the PWS was a home made system[4] based on the EEV39 CCD. We had two of them, both affected by hot pixels, and their main drawback was the controller whose readout system did not allow for frame rates higher than 100Hz. Furthermore the camera received commands only from a DOS PC through the serial port of a VME.

We took the opportunity of being doing such in deep changes at the level of the control system to renew also the wavefront sensor camera. The actual camera is a SciMeasure "Little Joe" system,[5] still based on the EEV39 80×80 pixel CCD. This camera has a much more compact CCD head, and the modularity and versatility of the controller allows for a wide range of readout modes and speeds. See Tab.1 for the specifics of the readout modes. The exposure time within the same program can be variated in multiples of a fixed value which depends on the readout mode. The minimum exposure time is defined by the frame rate of the program. At the moment we are using the program 0 with the CCD rebinned 2×2 and a frame size of 40×40 pixels. The exposure time of the CCD can be changed from the GUI without stoppping the loop. Data from the controller are received, processed and interpretated on the RTC via a PCI DV, from ETD Inc. frame grabber.[6]

3. LINUX REAL TIME

The new AdOpt@TNG RTC is based on a double processor architecture, developed under Real Time Linux, similar to the Subaru AO system[7].[8] One of the two processors is in charge of the loop, to calculate slopes, to calculate the voltages for the TT and the DM, and to send it to the digital output board. This board is a Power DAQ PDL–DIO–64ST, a PCI slot board, with 64 DI or DO (in banks of 16) with high speed streaming.[9] The board dispatches the signals towards the DM and the TT controllers. The other processor is devoted to the

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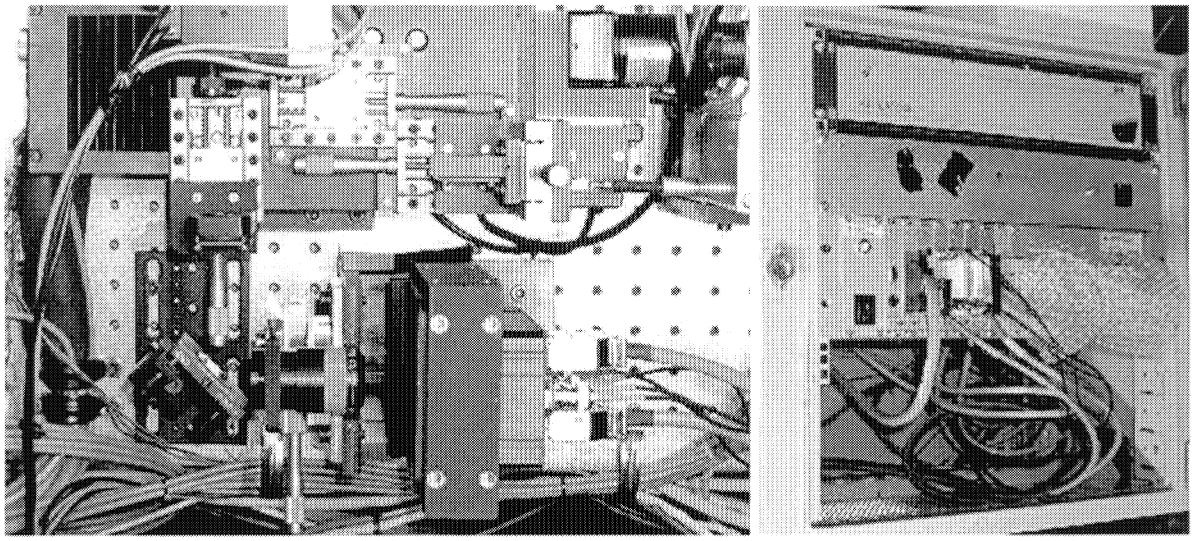

Figure 2. (Left) The SciMeasure CCD (at the bottom center, the dark rectangle with four screw holes) on the optical bench of AdOpt@TNG. Light is fed through the pyramid, a reimaging lens, a 45deg folding mirror, and a 0.1× optical relay to produce the right size pupils on the CCD. (Right)The Little Joe CCD controller mounted in the rack.

Table 1. Readout programs for the SciMeasure camera system. Exposure time and frame rate can be variated within the same program. The minimum exposure time is defined by the frame rate of the program.

Program	Actual Pixel Rate(kHz/port)	Image Size after binning	Binning	Filter	Filter TC(ns)	Actual Max Frame Rate(Hz)	Actual RON(e-)
0	203	40	2	4	1100	366	3.7
1	382	40	2	3	690	672	4.4
2	735	40	2	2	48	1239	5.8
3	1136	40	2	2	48	1826	6.4
4	204	80	1	4	1100	103	3.5
5	455	80	1	3	690	227	4.5
6	1136	80	1	2	48	564	5.7
7	2038	80	1	1	30	996	6.6

exchange of information and data between the loop and the other processes or the UWS. The UWS is now a Linux workstation doing the work that previously was done by a SUN and an HP stations. Picture 3 shows the overall layout of the control system.

3.1. The RTC Software

At the moment we use 3 software programs within the RTC, two of them in the **twcs** module, the wavefront command server and client, and one into the wavefront control module, **twfc**. Files are written on the disk of the USW which is cross mounted on the RTC, which means that the RTC will provide its same directory structure on the local disk.

- **twcsMain** this program is the command server. It waits for commands and executes them. The process is non real–time but communicates through a shared memory with the real time system. This process has to be started first in the beginning;

- **twcsMsgSend** this one sends commands to the **twcsMain** process. This program is spawned with a rsh from IDL whenever a command needs to be sent to twcsMain. It can also be used from the shell command

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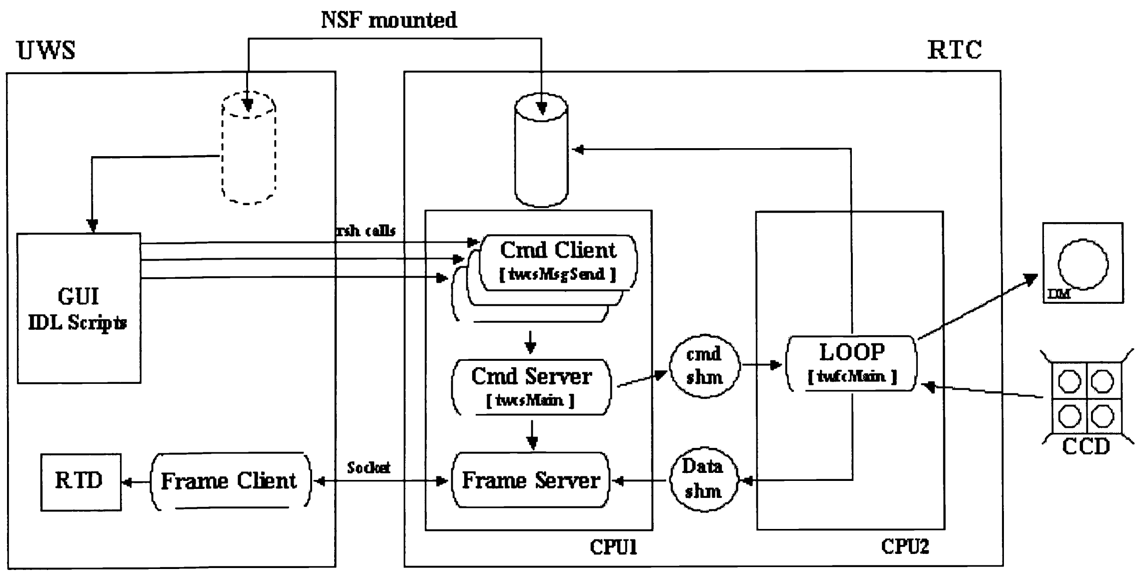

Figure 3. The schematic layout of the control system of AdOpt@TNG. On the UWS run the GUI with IDL scripts and the RTD. On the RTC one CPU is in charge of the loop, the other runs the Command Server which dispatches commands from the Command Client and to the shared memory.

line. Without a running **twcsMain** process nothing happens!

- **twfcMain** this program is executing the control loop. To create slopes or close the loop this program is needed. The process receives commands through a shared memory from **twcsMain**. It is not able to receive commands through any other way. **twfcMain** needs **twcsMain** running to be operated.

3.2. The RTC commands

Commands are sent with the **twcsMsgSend** program. Commands and command options are given as parameter with **twcsMsgSend**. For example, to load the default background file one can write the following from the command line on RTC:**twcsMsgSend LOAD BCKG**

The following commands exist up to now: **LOAD, SET, DO**. Each of them is used with some parameters to specify what is the required task.

LOAD is used to upload, through **twfcMain**, configuration files or the reconstruction matrix and the shared memory of the RTC is updated with new values. The new values are used in the next slope calculation. If no filename is provided the default file is loaded from the default directory. The first parameter of the command characterize the task and the directory from where files are loaded.

- **LOAD SUBP** [**filename**] Loads the starting pixels to which refer the position of the subapertures from the directory
DATA_ROOT/Setupfiles/subapPos.cfg, with ASCII format of 4 integers;
- **LOAD BCKG** [**filename**] Loads a background frame, made of 40 × 40 integers, in binary format from the directory:
DATA_ROOT/Setupfiles/Background/
- **LOAD FFLD** [**filename**] A flatfield frame is loaded from:
DATA_ROOT/Setupfiles/Flatfield/ It is made of 40 × 40 floats, in binary format;

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- **LOAD SLOPO** [**filename**] Loads slope offsets, 128 floats, in binary format, from: **DATA_ROOT/Setupfiles/Slopeoffsets/**;
- **LOAD CMTX_TT** [**filename**] Loads the TT control matrix, $2 \times 64 \times 2$ floats. The new control matrix is used with the next matrix calculation. It is loaded from: **DATA_ROOT/Setupfiles/ControlMTX_TT/**
- **LOAD CMTX_DM** [**filename**] Loads DM control matrix $97 \times 64 \times 2$ floats from the directory: **DATA_ROOT/Setupfiles/ControlMTX_DM/**
- **LOAD MIRMODE** [**filename**] Loads mirror modes from: **DATA_ROOT/Setupfiles/Mirmodes** in the format of 99 integers, one for each actuator plus 2 for the tiptilt, and applies them to the DM and to TT mirror. Any kind of mode can be loaded (zonal, zernike, KL, etc.). The absolute voltage is applied.

SET is used to set the mode in which the control loop is running or the status of the loop. One of the following options can be chosen between **SET MODE < READ, WRITE, TT, DM, FULL, TTWRITE, DMWRITE, FULLWRITE>** and **SET STATE <OFF, ONLINE, STEP, CLOOP>**.

- **READ**: reads CCD, calibrate frame and calculate slopes;
- **WRITE**: same as **READ** plus writes slope, subapertures and raw data file;
- **TT, TTWRITE**: same as **READ** or **WRITE** plus TT matrix calculation and applies TT voltages.Only TT loop is closed;
- **DM, DMWRITE**: same as **READ** or **WRITE** plus DM matrix calculation and applies DM voltages. Closes DM loop only;
- **FULL, FULLWRITE**: as **TT** and **DM** together in **READ** or **WRITE** mode;

The gain of the loop can also be controlled through the **SET DM_GAIN** [**value**] and **SET TT_GAIN** [**value**]. The frame rate of the CCD is changed through the **SET FRMR** [**Hz**] command, without the need of opening the loop.

DO is mainly used for engineering or diagnostic tasks, and allows to save full frames from the CCD or run the closed loop for some steps and if needed to save a full buffer of diagnostic.

- **DO IMAGE** [**filename**] [**number**] [**Comment**] -
  Does an image and save the raw and a fits frame into **DATA_ROOT/Data**, the default directory. Optional filename, number of images and some comment can be specified. If none of the options is specified the default name is used, one image is done and no comment is given to the fits file. Options can only be used in right order. Already existing file with same name is overwritten. File name is extended with a counter (4 digits) and the extension **.raw** and **.fits**, respectively.
- **DO STEPS <number>** The loop is closed for the given number of steps. Depending on the **MODE** set, the loop only reads, reads and writes files or reads and applies voltages to TT, DM or any other of the previous options.

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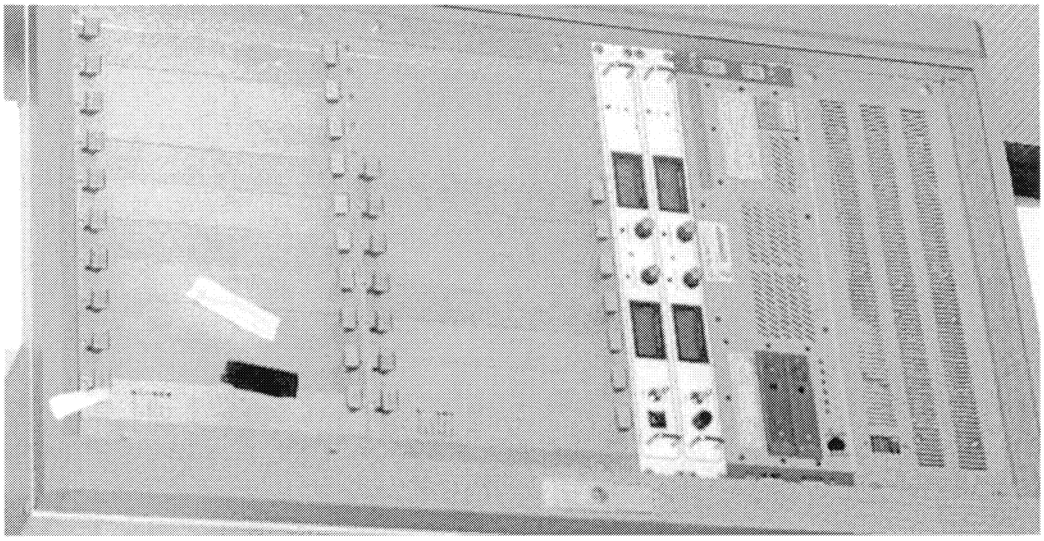

Figure 4. The rack hosting the Linux double processor RTC, the High Voltage amplifiers for the DM and the DM drivers. Next to the PC there are the electronic boards (not visible) to dispatch the electronic signals from the RTC towards the TT mirror and the DM.

4. THE REAL TIME DISPLAY AND THE GUI

A Real Time Display of the images collected with the CCD camera is fundamental for the alignment of the system and for some minor tasks. Real time for this purposes corresponds to a video frame rate of at least 10-15Hz. In order to minimize the amount of data transferred from the RTC to the UWS some changes have been implemented into the ESO–RTD[10] program.

A Frame Client and Frame Server routines have been created. As one can see in Fig.3, the Server runs on the RTC while the RTD and the Client run locally, on the UWS. The Server bufferizes the CCD images at the loop rate in the shared memory from where the Client took them when asked for. In this way only the data frame is transfered and not the whole display program thus saving processing time of the RTC and bandwidth.

The whole set of commands of the RTC can be given through the user interface running under IDL on the UWS, through buttons and pop–down menus. The IDL scripts are executed at the UWS and spawn via remote shell commands on the RTC. Automatic macro procedures go from the task of generating a simple background, flat field or slopes offsets file, to the reconstruction matrices. Status and mode of the loop are authomatically changed as needed. A special widget window is dedicated to check the status of the DM and to control each actuator individually, all together or to upload mirror modes files. The complete diagnostic of the control loop can be analyzed: pixels, slopes and dm commands can be downloaded from the RTC and processed.

5. THE INTERFEROMETER FOR THE DM

An interferometer is used to optically test the behavior of the Deformable Mirror (DM). The first step is to set the surface of the DM to a nearly flat status at the middle of the actuators' stroke range, by controlling each single actuator. This can be done in a zonal closed loop between the interferometer and the IDL GUI controlling the DM. Over the flat surface of the DM given modal aberrations can be introduced and the correspondence between the input and output map of the DM as well as the optical aberrations measured through the interferometer and through the PWFS can be cross–checked. The image quality also must be analized on the scientific camera and the throughput is increased to the maximum in terms of Strehl Ratio (SR) by removing the static aberrations of the optical relay. This is done introducing aberrations on the DM that increase the SR and defining the resulting surface map as the ideal surface to which the DM must converge.

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At the moment, a spherical unequal-paths Twyman-Green interferometer is used (see Fig.5(left)). A Single Mode Fiber (SMF) acts as a point-like source, instead of a traditional spatial filter composed by a microscope objective and pin-hole, and allows for obtaining a fringe pattern without noising speckles inside. At the common focus of the two optical paths, a card with a small pin-hole helps to clean up any spurious fringes caused by the beamsplitter.[11]

To avoid that the lens, used in front of the DM for collimating the beam, affects the result of the interference pattern because of its residual aberrations, to simplify alignment procedures and to obtain absolute measurement of such a flatness, a Fizeau interferometer[12][13],[14] like the one sketched in Fig.5(right), is going to be built and to be mounted in the AdOpt@TNG module in a few months.

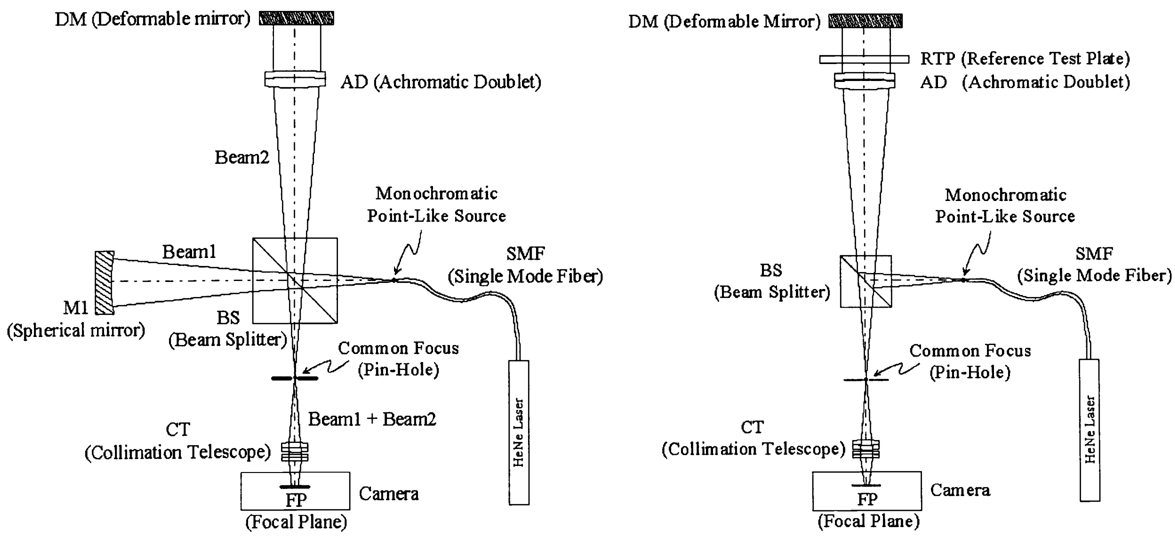

Figure 5. Two home–made interferometers for the DM behavior analysis; on the left the Twyman–Green actually mounted, and on the right the foreseen Fizeau interferometer.

For either type of interferometers, to get sharper fringe patterns, a collimation telescope should be set before the camera and focused on the surface of the DM.

6. THE PIGS EXPERIMENT

In july and november 2003 the groups of Max Planck Institute in Heidelberg, of Arcetri Observatory and of Durham University set up the PIGS experiment (Pseudo Infinite Guide Stars)[15] at the WHT telescope.[16] A Rayleigh Laser Guide Star (LGS) fired from a 4m class telescope is a scaling down of a sodium LGS for an Extremely Large Telescope. The AdOpt@TNG group also gave its contribute to the experiment with the making of the masks (see Fig.6) for the wavefront sensor. We used the milling machine that makes the MOS masks for Dolores,[17] the low resolution spectrograph of Galileo, to produce a mask with concentric rings. Properly placed at the focal plane of the telescope this mask produces an *angular gating* of the elongated Rayleigh spot, by selecting different directions of light from the LGS. The mask alone is sensible to radial (with respect to the optical axis) aberrations of the spot and another sensing device is used for the azimuthal aberrations. An autocad drawing of the mask was imported into the computer that controls the milling machine. The smallest width of the cut is defined by the size of the drill point to 200μm. The mask was lately cleaned from any impurity in an ultrasound bath with non–foaming soap, and sent to Heidelberg for mounting, alignments and tests on the optical bench before the on–sky experiment.

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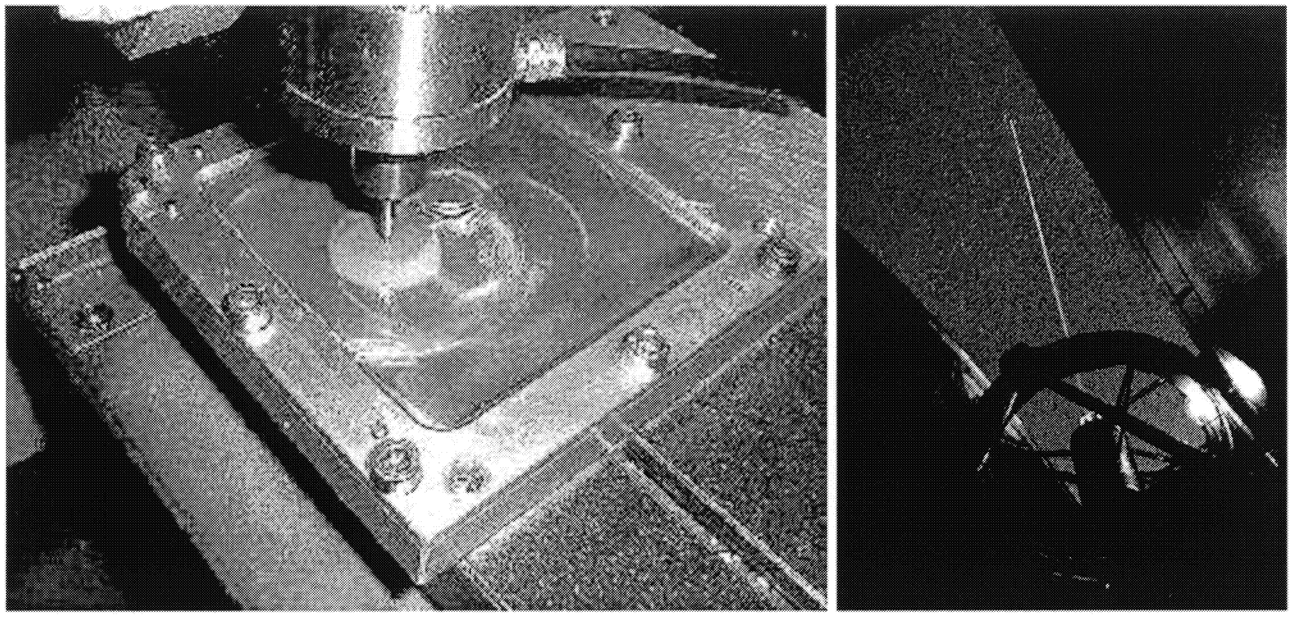

Figure 6. (Left)The mask for the PIGS experiment being milled at the TNG. (Right)The Rayleigh laser fired towards the Pleiades cluster from the WHT telescope

7. CONCLUSIONS

The new control system of AdOpt@TNG has shown to work in a robust way and the loop has been closed on the bench at the beginning of june 2004. We had to struggle a lot for the interface between the RTC and the DM electronics and some actuators are now dead, we don't know exactly why. We had a power failure on one of the Power Amplifier which broke the amplifier itself and probably two actuators. Nevertheless the AdOpt@TNG system is offered from the beginning of august 2004 to the astronomical community, first on a shared risk basis, in order to allow for fine tuning of the loop parameters and for the definition of the system characteristics, performances and limitations.

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