First Light Adaptive Optics System telescope commissioning plan with InfraRed Test Camera (IRTC)

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ABSTRACT

This document contains a description of the commissioning campaign for the First Light Adaptive Optics (FLAO) system at the LBT telescope. The activity is divided in five main parts, system unpacking and re-integration, system installation at the telescope, system calibration check and first light, system observing modes test in day-time and night-time, final system test on-sky. A description of the mentioned parts is given. A discussion of the day-time and night time required is reported together with a section on the commissioning campaign activity management.
## Modification Record

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## Abbreviations, acronyms and symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>LBT</td>
<td>Large Binocular Telescope</td>
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<td>MMT</td>
<td>6.5m MMT telescope</td>
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<td>FLAO</td>
<td>First Light Adaptive Optics system</td>
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<tr>
<td>AGW</td>
<td>Acquisition, Guiding and Wavefront sensing unit</td>
</tr>
<tr>
<td>AO</td>
<td>Adaptive Optics</td>
</tr>
<tr>
<td>W</td>
<td>On axis Wavefront sensing unit</td>
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<tr>
<td>LBT672a</td>
<td>First Adaptive secondary unit of LBT telescope</td>
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<td>PSF</td>
<td>Point Spread Function</td>
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<td>InfraRed Test Camera</td>
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<td>GUI</td>
<td>Graphical User Interface</td>
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<td>Telescope Control System</td>
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<td>Region Of Interest</td>
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<td>Field of View</td>
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<td>Real Time Reconstructor</td>
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<td>WaveFront Sensor</td>
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<td>Strehl ratio</td>
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<td>ADS</td>
<td>ADS International SRL</td>
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<td>IM</td>
<td>Interaction Matrix</td>
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1 Scope of the document

The document describes the various activities to be done in order to complete the First Light AO system telescope commissioning.

2 Applicable documents

3 Telescope requirement for FLAO commissioning

The telescope bent Gregorian focal station should be aligned before starting the AO system commissioning. The following specifications should be followed in order to have a correct operation of the FLAO system:

1. Telescope optical axis with the LBT672 adaptive secondary installed and in SL (seeing limited) configuration should be aligned to the de-rotator axis following the standard procedure developed for the rigid secondary by LBTO.
2. Telescope focal point should be centered within the AGW unit FoV with an accuracy of ~2mm.
3. Input F/# of the bent Gregorian optical train telescope should be 15 +/- 0.3
4. The FLAO system performance will depend on the amplitude of telescope vibrations causing beam jittering at Gregorian focal station level. An estimate of the requirements in terms of maximum RMS error and bandwidth of these tip-tilt errors is beyond the scope of this document. At this level we mention that the FLAO system will be equipped with the capability of implementing both a controller based on WFS data [RD1] and one based on internal accelerometers [RD2] to correct the tip-tilt error caused by telescope structure vibrations, moreover during the solar tower tests phase [AD5] these methods will be tested.

4 FLAO system unpacking, re-integration and functional check

Shipping, unpacking and re-integration of the two main subsystems: the adaptive secondary mirror or LBT672a and the AO system wavefront sensor or W unit will be done in parallel. The tasks to be done for these two units are reported below:

4.1 LBT672 shipping notes unpacking and re-integration

The LBT672 unit (mounted on its integration stand), the mirror shell and the spider-arm cabinet are shipped to the mountain in three different boxes. A separate fourth box containing cables is under discussion. After traveling to the U.S. the shell will first receive the Al coating on its front surface, this operation will be done in Tucson at the Sunnyside coating facility. After coating the shell will be packed and shipped to the mountain according to a local transportation procedure (TBC). The shell will arrive on the mountain with its magnet side facing up (concavity facing down), this is the orientation is required for starting the procedure of mounting the shell on the secondary unit. The LBT672 box is opened and the unit is moved inside the clean-room at the assembly-and-test facility on the mountain. The spider-arm cabinet is moved near the LBT672 unit. The cables and cooling are installed and a functionality test without shell is performed. The shell is then mounted following the “Procedure for the installation of the thin shell on LBT672 unit” (646a009). Functionality with shell is tested. (8 days)

4.2 W unit shipping notes

The shipment of AGW unit will be done in the following way: the WFS board will be shipped in a small separate box. The box will have internal insulation against shocks. The WFS optics will be kept in place except for the (1) the glass pyramid 2) the tip tilt fast steering unit including piezo-electric stage and mirror (3) the camera lens positioner including camera lens and piezo-electric stage (4) the beam splitter cube located in the auxiliary unit bench These four parts will be shipped separately due to their sensitivity to shocks. Separate shipping of the pupil rotator is now being considered because of the strict requirements on the alignments of the mirrors combination installed in the rotator unit. The problem in removing this unit is the sensitivity of the WFS alignment to the pupil rotator axis position. Electronics: the two CCD heads will be shipped separately because of their extreme sensitivity to shocks. In particular boxes with
foam insulation should be used to ship the two CCD heads. The electronic boxes will be shipped attached to the AGW frame as they will be during telescope operation. The cabling of the unit will be shipped together with the AGW unit as it will be during telescope operations. All the spare parts should be shipped in a separate box.

4.3 W unit re-integration

The W unit re-integration should take place in an optical lab. An optical bench should be provided. Dimension of the optical bench can be 1.5x1.5m. The WFS board components shipped separately will be re-installed on the WFS board. An internal optical alignment of the board will be done using an external fiber provided by the Arcetri group. After re-alignment of the WFS board the unit will be installed in the AGW structure. The WFS board alignment with the center of the mechanical structure will be checked. The alignment of the WFS reference source to this axis will be checked and readjusted if needed. After completion of the WFS re-alignment and installation in the AGW unit the W unit is ready for the functional test. A functional test of the unit will be done accordingly to the procedure already used during the W unit acceptance test in Arcetri. (8 days)

4.4 Functional checks of the FLAO system

A functional check of the full AO system will be performed before installing it at the telescope. To do this a temporary data communication (fiber link) will be installed between the adaptive secondary and the AGW unit. The system will then be connected to the AO supervisor computer in order to test its basic functionalities. A compliance matrix should be compiled to have a report of the available functionalities of the system. A test of the SW interaction with the TCS should be performed at this early stage of the commissioning activity to start as soon as possible if needed any action of SW additional coding or adaptation. This last phase is not included in the two days period dedicated to functional checks and could be done in parallel with the other operations. (2 days)

5 Telescope installation of subsystems

5.1 Adaptive secondary installation and functionalities

The spider-arm cabinet is mounted on the telescope spider-arm. In parallel the hub, mounted on its transport bench, is placed close to the integration stand of the LBT672 unit. The Hexapod is mounted in the hub following procedure 646a013a ("Procedure for Hexapod installation into the hub"). Then the LBT672 unit is mounted in the hub following the procedure 646a015a ("Procedure for LBT672 installation into the hub"). The integrated hub is moved with its transport stand in the dome and the hub is installed on the telescope following procedure 646a018 ("Procedure for M2 installation on the telescope"). Cables and cooling is connected and functionality checks done. The optical alignment procedure for the LBT672 unit is derived from the procedure used by the LBTO team for the optical alignment of the rigid secondary mirror. During the alignment procedure, the adaptive mirror can be set to the seeing-limited configuration (equivalent to the LBT rigid secondary mirror) when needed. (3 days)

5.2 AGW installation and functionalities

The procedure to install the AGW unit on the de-rotator of the bent Gregorian focal station will be the procedure already followed by the LBTO team and AIP team to install the AGW unit. (2 days)

5.3 Infrared test camera installation and functionalities

The infrared test camera will be installed on the FLAO system AGW unit. The installation procedure should be the same used by LBTO team to install the IRTC for the alignment campaign of the bent Gregorian focal station. The IRTC functionalities will be tested with particular attention to interaction with the AO supervisor and with the main control SW. (3 days)

5.4 Retro-reflecting optics installation

The prime focus camera swing arm is fully opened. The M2 swing arm is opened. The opening stop of the M2 swing arm has been previously regulated in order to avoid collision of the retro-reflecting optics holder structure (ROHS) with the prime focus camera when mounted. The telescope is set horizon pointing (service configuration). The service platform is raised to the secondary level and the interface flanges for connecting the ROSH are installed to the
hub. The ROSH is lifted with the crane and handled by the operators on the service platforms to be connected to the hub, a procedure for this installation is not yet available. \(2 \text{ days}\)

### 5.5 Alignment of AGW unit with retro-reflecting optics using the secondary hexapod

The alignment of the FLAO system should be done in two parts: in the first part the LBT bent Gregorian focal station should be aligned to have the telescope optical axis coincident with the de-rotator axis. This part of the work will be executed by the LBTO team. After this alignment has been done the W unit will be aligned to have the W unit optical axis coincident to the de-rotator optical axis. When the alignment condition is reached the system is ready for calibration checks. \(5 \text{ days}\)

### 6 System initial calibration and first light on sky

The AO system will arrive on the mountain with a set of look-up tables and data sufficient to provide initial on-sky operations. The most important calibration elements are the system interaction matrices (IM) and reconstructor and the WFS slope null vector (both elements are measured during the solar tower test and depends on tilt modulation and WFS CCD binning).

#### 6.1 Pupil geometry registration

Before the IM and slope null vectors acquired during the solar tower test can be used at the telescope the WFS pupil geometry has to be properly registered (AD3). The pupil geometry is registered when pupil diameters, centers and WFS focus are placed accordingly to the WFS requirements (AD1, AD3). A correct pupil registration is clearly needed before to start any new measurements of IM at the telescope. \(2 \text{ days}\)

#### 6.2 Infrared test camera PSF optimization

After achieving the nominal registration parameters the closed loop test can be done by using the IRTC (AD28, AD29). In order to achieve the best AO system performance non common path aberration between the WFS and the IRC has to be corrected. The main non common path aberrations are low order aberrations. The secondary shape will be changed to optimize the SR on the IRTC. Then a corresponding set of slope null will be measured at the WFS. This slope null set is the one that will be used during on sky observations. In this procedure differential tilt and focus will be adjusted by using the WFS main stages. \(3 \text{ days}\)

#### 6.3 Initial day-time closed loop test and system interaction matrices measurements

After WFS is registered in the same configuration used in the solar tower initial closed loop test will be done. The system calibration needed to operate the system will be taken initially from the set of data measured in the solar tower test [AD5]. The aim of this test is to measure the system performance as a function of photon flux (or CCD counts) and seeing conditions \((r_0, t_0)\). To simulate different seeing conditions some pre-computed disturbances will be injected in the secondary actuators positions. The system performance will be measured in terms of PSF SR and FWHM (AD1). System performance achieved will be compared with the performance achieved at the solar tower in Arcetri. Some measurements of the interaction matrices will be done again at the telescope to check that the calibration achieved in the solar tower still provides optimal performance. The number of required measurements to provide the proper set of calibration data will be decided on site after analysis of the achieved closed loop performance. After acquisition of the needed interaction matrices closed loop test with solar tower and LBT measured calibration data will be done and performance compared. Once that the best set of calibration data is identified the system will be ready for on sky operations. \(10 \text{ days}\)

#### 6.4 AO system control SW test including TCS interactions

The full AO control SW (AD4, AD15) to be used during FLAO observations including the IRTC operation will be tested in day time. A test of the SW interaction with the TCS will be done as well (AD14). In particular a test of the mode offloading and pupil rotation tracking procedure should be done in order to have the AO system able to work safely and efficiently during telescope operations. \(5 \text{ days}\)
6.5 First light of AO system on sky in engineering mode

The first on sky test of the system will start by testing the star acquisition procedure. A check of the WFS registration (AD3) will be done after a successful star acquisition. Because the system pupil is the secondary mirror we do not expect to have large pupil displacements when passing from the calibration optics (using secondary and tertiary) to the complete optical train of the telescope. Moreover using the camera lens translation stage a displacement of about +/- 5\% of the pupil can be corrected. The next step is measuring/checking the WFS counts for a given star magnitude. Then a set of closed loop test, using the engineering interface, will be done by measuring the closed loop system performance (SR and FWHM on the IRTC) as a function of the WFS counts or reference star magnitude. Initially bright reference star will be used and then moving to faint reference star. In this phase the AO system configuration will be done interactively using the engineering interface and the look up tables built during the solar tower test. An estimate of the seeing conditions will be very important in this phase to compare the achieved results with numerical simulation estimate. We expect to use the two first nights for the star acquisition, pupil registration check, alignment refinement, measurement of WFS CCD counts versus star magnitudes, and the two last nights for the closed loop test. (5 nights)

7 AO system observing modes and on sky test

7.1 Day time test

7.1.1 Closed loop test

After data reduction of the closed loop data of the first night time observations a new set of interaction matrices will be measured if needed. Some daytime test mostly devoted to faint reference star magnitude will be done. (5 days)

7.1.2 Observing modes test

During daytime the observing modes of the AO system will be tested as much as possible using the IRTC and the full AO system SW. The test have the aim of showing that the AO system SW is able to perform the AO system configuration properly once that it receives the correct input parameters. The system observing modes are listed here

1. Seeing limited Mode (SLM). (2 days)
   In this mode the system is idle and the adaptive secondary is maintaining a fixed shape during observations. Different mirror shape could be loaded depending on the instrument that is used to observe.
2. Field Stabilization Mode (using standard PI and Kalman filtering)(FSM). (5 days)
   In this mode the secondary is correcting tip and tilt. This mode is available to LUCIFER in both seeing limited and diffraction limited configuration. This observing mode could be extended to other instruments having their on tip tilt sensor.
3. AO modes ACE & ICE (AOM). (8 days)
   These are the two AO observing modes. The first one (ACE) provides an automatic configuration of the AO system while the second one (ICE) provides an interactive way of changing a few parameters of the AO system configuration. This last observing mode SW allows the system to optimize the configurations achieved by using the look up table doing an on sky data acquisition to optimize a few AO system parameters.

7.2 Night time test

After day time test completion a new set of observing nights is planned. Closed loop test in engineering mode will be done in particular with faint reference stars (5 days). Then on sky test of the AO system observing modes will be done requiring a total of five nights. As listed below

4. SLM 2 night
5. FSM 4 nights
6. AOM 6 nights
8 Final commissioning test of the AO system

A period of data reduction should be done prior this final phase. This is done to assess the AO system performance on sky in order to identify possible issues to be solved before the final measurements. For this reason this final phase should be separated by at least two weeks from the previous one.

8.1 System performance in engineering mode

The observing period will start by doing observations with the AO system in engineering mode to measure the closed loop performance. This final task should provide the best AO system performance (SR & FWHM with IRTC) as a function of the reference star magnitude. The achieved performance will be compared with the numerical simulations done with the seeing values experienced in the observing nights. The data reduction should demonstrate that the system can achieve the baseline performance stated in AD1. After this performance test the observing modes of the system will be tested in terms of system performance. (4 days)

8.2 Observing modes SLM and FSM

Night observation in SLM and FSM will be done and the achieved results will be compared with the simulated result at the seeing value experienced during observations. The achieved data should demonstrate that the system is reaching the baseline performance reported in AD2. (4 days)

8.3 Observing modes AOM

Night observation in the two observing modes (ACE, ICE) will be done and the achieved results will be compared with the simulated result at the seeing value experienced during observations. The achieved data should demonstrate that the system is reaching the baseline performance reported in AD2. The achieved performance will be compared with the performance measured when the system was operated in engineering mode. (6 days)

9 Telescope time required for system commissioning

The total time required for system commissioning is of 52 days and 36 nights. This commissioning period is divided in five blocks as described above. The total period of time to have 88 days of operation is found to be 123 days. This is done assuming a working schedule of 5 days a week. In this computation an observing night has been compute as a full day. In other words no daytime and night time activity has been accounted in the same day. In this way the full commissioning period is of 4.1 months.

10 Telescope commissioning activity management

A schedule of the commissioning campaign is provided below. The campaign is divided in five main phases. The phases are broken down in tasks whose names are taken from the sub-sections of this document: unpacking, re-integration and functional checks, telescope installation of subsystems, initial calibration and first light on-sky, AO system observing modes, final commissioning tests. The duration of the commissioning campaign is 88 working days. The start and finish date are 22/12/2009 and 22/04/2010 respectively for a total period of 4 months. Some idle time between phases can be accommodated to merge the commissioning activity with the other telescope tasks, in this case the commissioning campaign will be spanning a longer time. The commissioning campaign schedule is reported in Figure 1.
Figure 1 The Gantt chart of the commissioning campaign. The five phases do not need to be executed one after the other. They are reported one after the other with no time lag for simplicity.

The main management elements of the listed phases are summarized in Table 1
## FLAO commissioning activities

<table>
<thead>
<tr>
<th>phase duration (days)</th>
<th>system unpacking, re-integration and functional check</th>
<th>Telescope installation of subsystems</th>
<th>System initial calibration and first light on sky</th>
<th>AO system observing modes and on sky test</th>
<th>Final commissioning test of the AO system</th>
<th>Total FTE per group</th>
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Table 1: The five main phases of the FLAO commissioning campaign. The central area in light gray reports the number of persons on duty at the telescope from the Arcetri group. ASM is the adaptive secondary group. W is the W unit group, SW is the software group, NS is the numerical simulation group. ADS and MG identified people form ADS and MicroGate. The total FTE per group over the campaign is reported in the left column. Total number of person at the LBT site is also reported.

We consider that the personnel from Arcetri AO group will be rotating during the commissioning period so that the number of person listed in Table 1 will be covered by different people at different times. The Arcetri AO group has available 14 personnel units so that about 50% of the group will be at the telescope during the commissioning period.