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Authors

Hackenberg, Wolfgang
Bonaccini Calia, Domenico
Guidolin, Ivan
et al.

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Progress report on the ESO 4LGSF

W. Hackenberg[a], J. A. Abad[a], J. L. Alvarez[a], J. Beltran[a], D. Bonaccini Calia[*,a], B. Buzzoni[a], M. Comin[a], D. Del Valle[a], P. Duhoux[a], C. Dupuy[a], G. Fischer[a], F. Gago[a], I. M. Guidolin[a], R. Guzman[a], P. Haguenauer[a], A. Haimerl[a], R. Holzloehner[a], S. Huber[a], L. Kern[a], A. v. Kesteren[a], J. P. Kirchbauer[a], H. Kuntschner[a], S. A. Lewis[a], J. L. Lizon[a], P. Y. Madec[a], S. McLay[a], I. Munoz[a], J. C. Palacio[a], T. Pfrommer[a], J. Pirard[a], D. Popovic[a], M. Quattri[a], J. Quentin[a], R. Ridings[a], M. Riquelme[a]
[a]European Southern Observatory (ESO), Karl-Schwarzschild-Strasse 2, D-85748 Garching, Germany

ABSTRACT

The Four Laser Guide Star Facility (4LGSF) is part of the ESO Adaptive Optics Facility (AOF), in which one of the VLT unit telescopes, UT4, is transformed in an adaptive telescope - equipped with a deformable secondary mirror, two adaptive optics systems at the Nasmyth foci and four laser guide star modular units. In this poster we present the key results of the acceptance tests performed on the 4LGSF in Europe and first commissioning results obtained with the Laser Guide Star Unit #1 in stand-alone operation.

Keywords: Adaptive Optics Facility, sodium laser guide stars, laser launch telescope, laser pointing camera, laser guide star spot size, laser guide star brightness

1. INTRODUCTION

The 4LGSF is a subsystem of the Adaptive Optics Facility (AOF) on UT4 of the ESO VLT ([1]), to provide the adaptive optics systems/instruments GALACSI/MUSE and GRAAL/HAWK-I with four sodium laser guide stars, as artificial reference sources for the high-order AO corrections.

For the 4LGSF, four modular LGS Units (LGSUs) are deployed at the UT4 Centerpiece (see Figure 1 and Figure 2). Each LGSU consists of the Launch Telescope System incl. 22-W 589-nm Laser Head and two close-by cabinets, one hosting the Laser Unit electronics (incl. the pump fibre laser module) and the other containing the local control electronics incl. safety interlock system sub-station. Two additional 4LGSF cabinets are installed on the 4LGSF Platform underneath the Nasmyth B Platform and contain the computers for independently controlling the four LGS Units and the common Safety Interlock System (SIS). The 4LGSF Platform also hosts the water-water Heat Exchanger (HEX) cabinet for the cooling of the Laser Units to a constant temperature of 15±1 deg C.

In Figure 3 the 4LGSF is depicted from the functional point of view (see [2] and [3] for further details). Key features of the 4LGSF and recently accomplished project milestones plus the ones planned in the short-term future are summarized below:

- Four sodium LGS (D_{2b} re-pumped), steerable off-axis up to 5';
- LGS flux $5x10^6$ photons/s/m^2 @ Nasmyth focus (specification for zenith and median sodium column density);
- LGS FWHM 1.4" (long-exposure) on AO WFS (specification for 1.0" seeing at zenith);
- Blind pointing accuracy of ±2.5" peak-to-peak (FoV of AO WFS) achievable with Laser Pointing Camera (LPC, [4]);
- LGSU#1 installed in 1Q2015 and stand-alone commissioned in 2Q2015 [5]; first LGSU#1 commissioning run with GRAAL conducted in 3Q2015;
- LGSU#2-4 to be installed in 1Q2016, stand-alone commissioning of complete 4LGSF scheduled for 2Q2016.

*dbonacci@eso.org

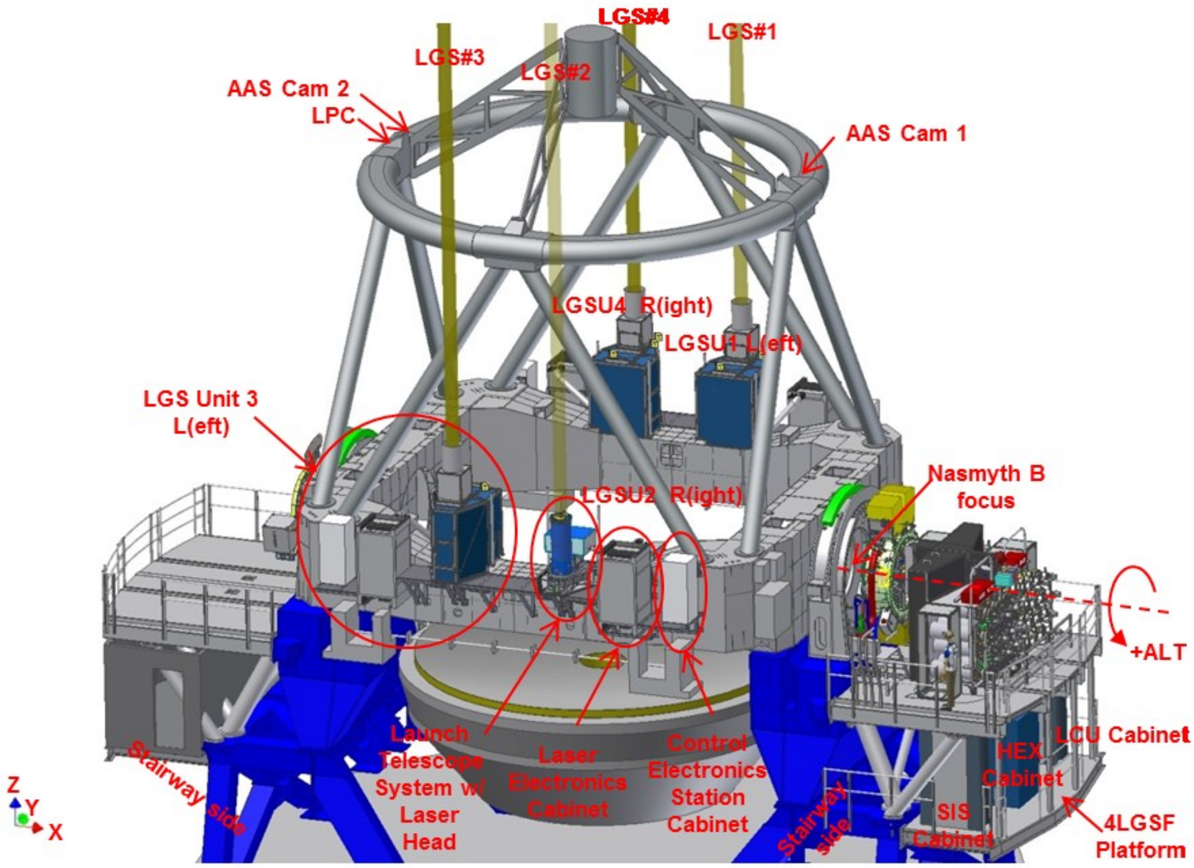


Figure 1: 4LGSF installation overview. There are three main installation locations at VLT UT4: on the Centerpiece, Topring and 4LGSF Platform underneath the Nasmyth B Platform. Beside the four Launch Telescope Systems (each including a Laser Head), in total 8 cabinets are installed on the Centerpiece for the laser electronics (incl. pump lasers) and local control. Furthermore, connection and distribution boxes are mounted on the Centerpiece for the power and cooling supply. On the 4LGSF Platform two cabinets are installed containing the control computers for the four LGS Units incl. Housekeeping and the Safety Interlock System. The 4LGSF Platform also hosts the water-water Heat Exchanger (HEX) of the laser cooling system. On the UT4 Top-ring the LAN smart-cameras of the Aircraft Avoidance System (AAS) as well as the Laser Pointing Camera (LPC) are mounted.

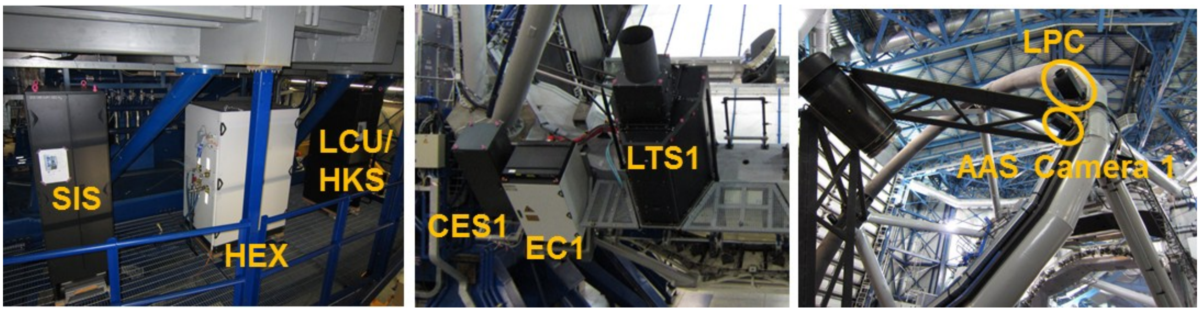


Figure 2: Already realized 4LGSF installations on the 4LGSF Platform (left), at the UT4 Topring (right, with new LPC) and at the Centerpiece (middle – fully equipped LGSU1). Mass dummies are currently installed at the remaining LGSU2-4 locations at the Centerpiece, with the final interfaces for the supply lines (cooling, power) and control lines already prepared. The mass of each LGSU at the Centerpiece is approximately 1.8 tons excluding support structures and floor grids. This mass is also the result of earthquake safety and stiffness requirements and the fact that solely water-water cooled cold plates are installed (no rotating fans for air ventilation are allowed at the telescope tube).

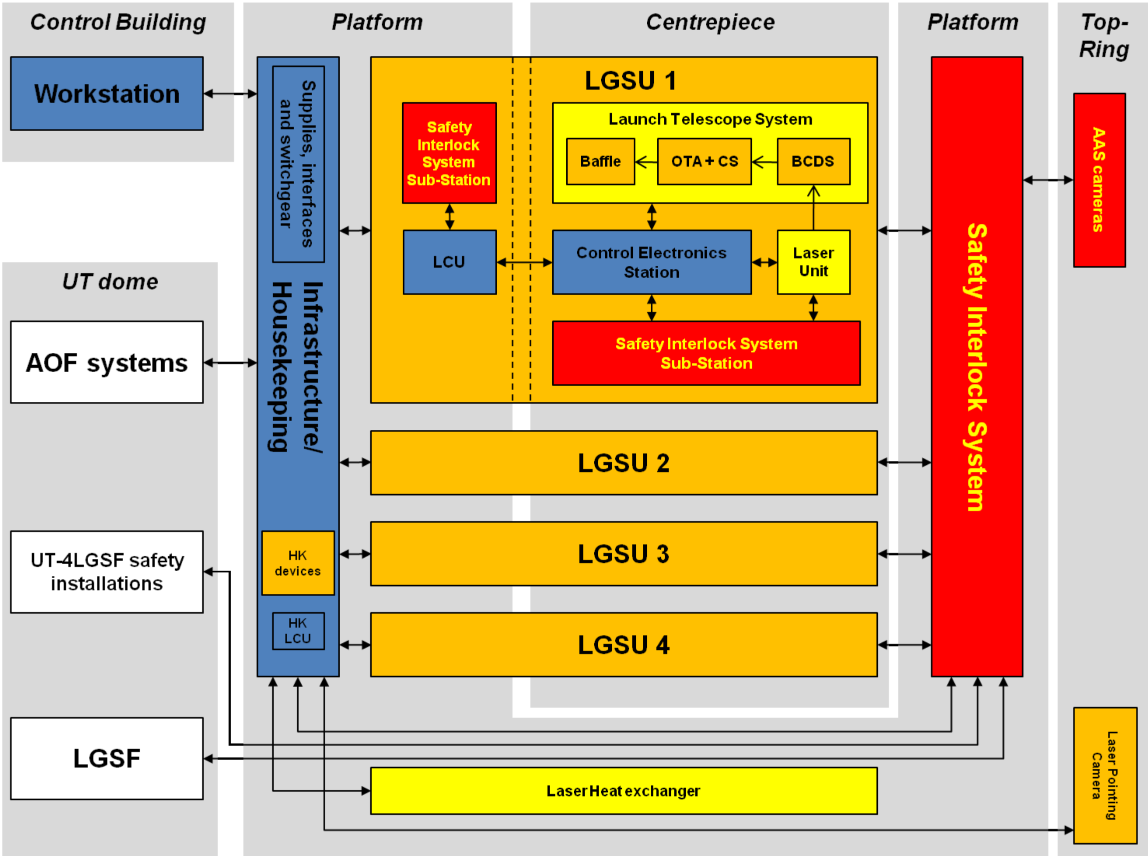


Figure 3: 4LGSF functional overview. The 4LGSF consists of seven main subsystems: four LGS Units (LGSU) with associated Local Control Units (LCUs), the Housekeeping (HK) System, the Safety Interlock System, with interfaces to the Workstations, AO instruments and the existing single-LGS Facility at UT4, respectively, and the Laser Pointing Camera. The Aircraft Avoidance System (AAS) is shared between LGSF and 4LGSF. The location of the various 4LGSF subsystems at the telescope is indicated by the top labels. CS = Cover Shutter; BCDS = Beam Control and Diagnostics System; OTA = Optical Tube Assembly.

2. 4LGSF EUROPE TEST RESULTS

Following a detailed test plan, each individual LGSU was subjected to comprehensive functional and performance testing in Europe after assembly and alignment ([6]). 4LGSF system tests were conducted with two LGSUs operating simultaneously while the remaining ones were used in simulation mode. In the following the key performance test results are summarized. The positive results achieved are qualifying the 4LGSF for shipment to Paranal Observatory. LGSU#1 was shipped in advance of the Provisional Acceptance Europe of the complete 4LGSF in order to conduct critical tests (mainly on-sky but also UT4-cooling and safety related) on LGSU#1 that can't be carried out to full extent in the ESO Garching laboratories but only in the target environment. This approach of a two-phase shipment allowed to maintain the possibility of retrofitting the remaining three LGSUs still undergoing their final tests in Garching should the need have arisen.

The tests of the LGSUs were comprising the following qualification and inspection steps (Table 1). Essential infrastructure required for the Europe tests and part of the 4LGSF Europe Test Facility at ESO HQ in Garching was a $9m^3$ thermal chamber (1-20 °C) and a launch telescope tilt stand. The latter was fitting into the thermal chamber and allowed extreme tilts down to horizon in both directions.

Table 1: Overview of tests and inspections carried out for the 4LGSF LGSU acceptance in Europe.

Item	Test type	Reference
BCDS flat optics	Optical quality measurement of items (incl. spares) with MiniFiz and Fisba interferometer at low laser power, optics pre-mounted and under steady-state temperature load T=1-20°C. High power laser tests on coating samples	
BCDS periscope	Pointing stability measurement with Fisba interferometer at low laser power under temperature loads and extreme tilts Z=±60° (zenith distance)	
BCDS focusing Beam Expander Unit (BEU)	Optical quality measurement incl. focus pre-calibration with Fisba interferometer under steady-state temperature loads T=1-20°C as well as 0.7K/h gradients, at full laser power (warming and cooling), for acceptance of contracted item	
BCDS Jitter Loop Mirror (JLM)	Range, resolution and step response measurement with position-sensing device (PSD) at OTA output and mirror position feedback sensors, T=1-20°C, Z=0°. Pointing calibration with PSD	
OTA	Full subsystem tests, for acceptance of contracted item	
OTA Field Steering Mirror (FSM)	Range, resolution and step response and pointing jitter measurement with Duma AlignMeter resp. PSD and mirror position feedback at OTA output, T=1-20°C, Z=0°. Pointing calibration with Fisba and AlignMeter	
BCDS Mirror Shutter	Burn-in (100 open-close cycles, each 0.5h powered open), T=1-20°C, Z=0°,±60°	
Launch Telescope System (LTS) Wind-Protection Cover incl. Cover Shutter	Light-tightness inspection of Cover System, Cover Shutter burn-in, T=1°C, Z=±60°	
Laser Unit	Full subsystem tests, for acceptance of contracted Laser System	
LTS output beam	Interferometic wavefont error measurement in double pass with Fisba and Phasics, at low and full laser power, T=1-20°C as well as 0.7K/h gradients, Z=0°-±60°, field angles ϕ=0, ±4.8’, without and with LTS Cover Baffle Optical polarization and intensity profile measurements with Thorlabs Polarimeter, at full laser power, T=1-20°C, Z=0°,±60°, ϕ=0 Throughput and emitted power measurements with calibrated photodiodes/bolometer Pointing repeatability measurements with cross-referenced and pre-calibrated blind-pointing reproducibility test setup, T=20°C, Z=0°-±60° LTS Crane Handling test: verification of beam quality (and hence alignment) with Fisba interferometer before and after handling	[6] Figure 4 Figure 5 Figure 6 Figure 7

Item	Test type	Reference
	(Dedicated test at UT4 conducted during AIV Europe: LTS Baseplate re-positioning error measurement at Centerpiece using electronic inclinometer and small helping telescope observing natural guide stars from Baseplate)	
LTS automatic focus control	Double-pass interferometric verification of focus control loop, at full laser power, T=1-20°C, Z=0	Figure 5
LGSU cooling system	Functional and performance test, also at extreme cabinet and LTS tilt, 10bar overpressure test for 1h	
LGSU	Vibration test with accelerometers, Laser Output Shutter, Mirror Shutter and Cover Shutter actuated	
Laser Pointing Camera	Functionalities, operation vs environmental conditions, calibrations of the CCD, calibration of the photometric mode, surface temperatures, burn-in tests	Article in this proceedings
LGSU control electronics	Functional test, power consumption, EMC test, with all actuators moving and laser powered	
LGSU safety interlock system	Functional test (~100 signals)	
LGSU control software	Functional and performance tests incl. interfaces with AO	
LGSU interfaces, labels	Inspections	

The optical tests done on LGSU#2-4 were a reduced set with respect to the ones carried out on LGSU#1. The fact that each LGSU is copy of each other and that the optics was produced from the same batch led expectedly to very similar optical performance test results for all four LGSUs. The Laser Head output beam parameters such as power, amplitude noise, optical quality and spectrum were measured all in specification, under operational and environmental conditions and for operating hours in excess of hundreds of hours. The optical quality and beam polarization of the LTS (incl. Cover system) are measured better than specified. The athermalized design of the OTA opto-mechanics is key in keeping the measured focus error in specification, with the help of the automatic focus control which takes care of air pressure changes in the OTA and the laser thermal load on the refractive elements of BEU and OTA.

The aim of the successfully concluded 4LGSF system tests in Europe was to demonstrate operability and stability of operation of the hardware and software. Due to the early installation of LGSU#1 (incl. part of the common 4LGSF hardware) at UT4 and infrastructure limitations in the Garching laboratory, the 4LGSF system tests in Europe were conducted only with part of the subsystems including a clone of the housekeeping and safety interlock system (serving as spares pool in the future). The real hardware of two LGSUs at a time could be controlled and exercised, LGSU#2+LGSU#3 and then LGSU#3+LGSU#4. During the automated software tests, the sensor inputs and software devices of the other two LGSUs were kept in simulation mode in the control software. This allowed to assess the full computational load. The safety interlock system could be tested with all available signals, even if some LGSU were in simulation mode. All three remaining Laser Units could be used for the system tests in the laboratory.

The 4LGSF system tests in Europe included the simulation of 14-hours observing nights in the laboratory, with the AAS and LPC cameras operated in simulation or in dummy mode for the SIS, respectively. For each simulated observing night the software templates foreseen for the later regular remote operation of 4LGSF at UT4 were used. The latter comprises the automated start-up (and shutdown) with health checks as well as the fully software-controlled LGS acquisition sequence incl. LGS preset pointing at the requested LGS asterism, wavelength detuning for WFS background calibration and LGS jitter loop closure (using simulated input data for the duration of a typical AO science observation block for the Europe test case). It is worth noting that the fully automated start-up of the LGSU ensemble from (power-saving) idle mode to ready (for propagation) mode takes less than 5 minutes when the cooling system is kept running after the previous shutdown.

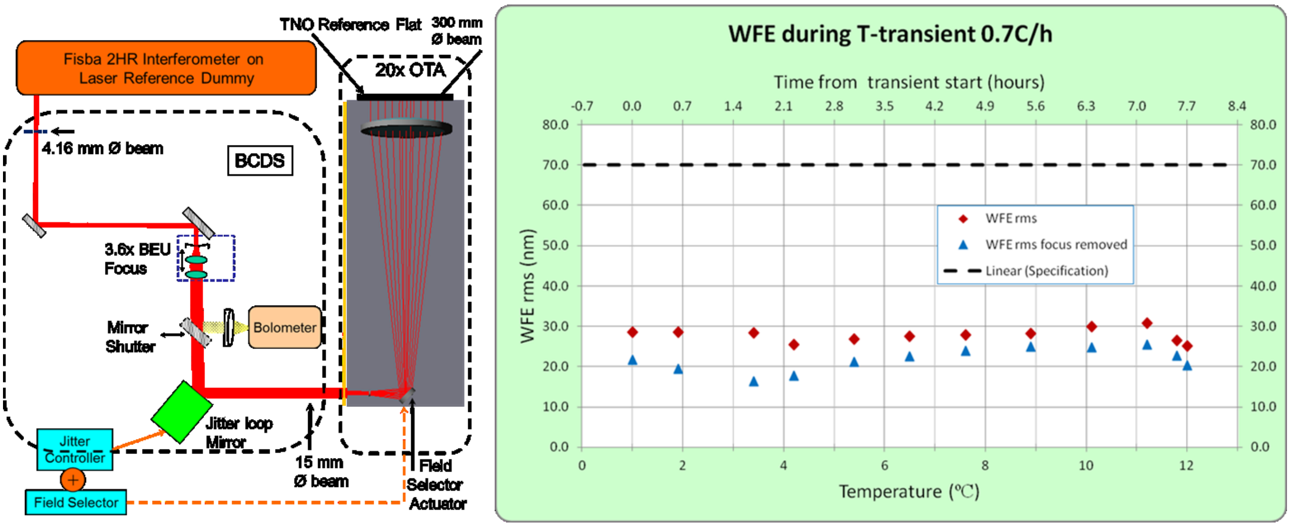


Figure 4: Left: sketch of LTS low-power optical test setup. Right: Measured wavefront error of LTS#1 at low power) during temperature transients between 1 and 12°C, at 0.7 ºC/h.

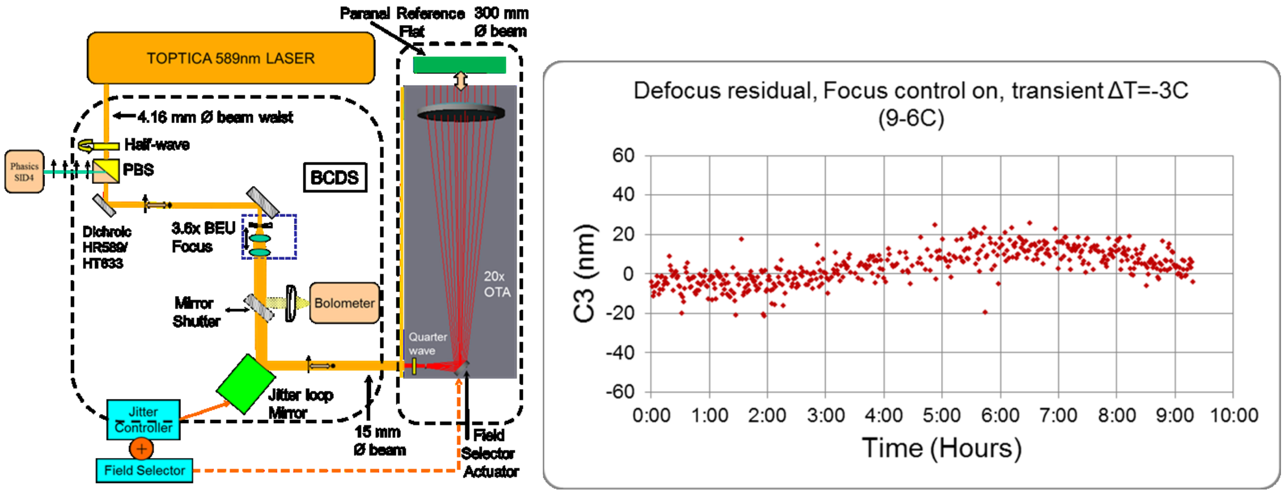


Figure 5: Left: sketch of LTS high-power optical test setup. Right: the measured wavefront error under high power laser load is dominated by defocus, the higher order aberration terms are negligible (<10 nm RMS). The focus control loop not only has to correct for optics' temperature changes caused by the laser load but also for environmental changes such as air pressure variations.

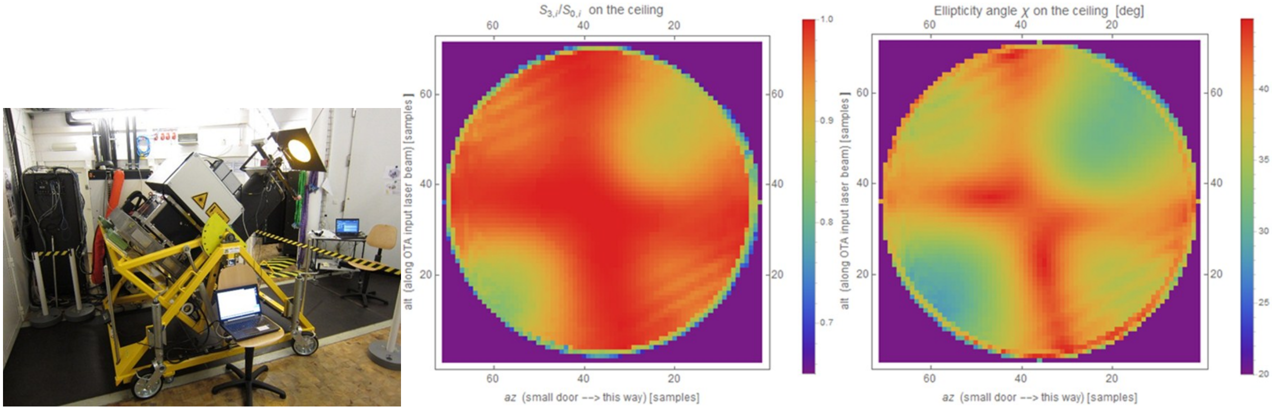
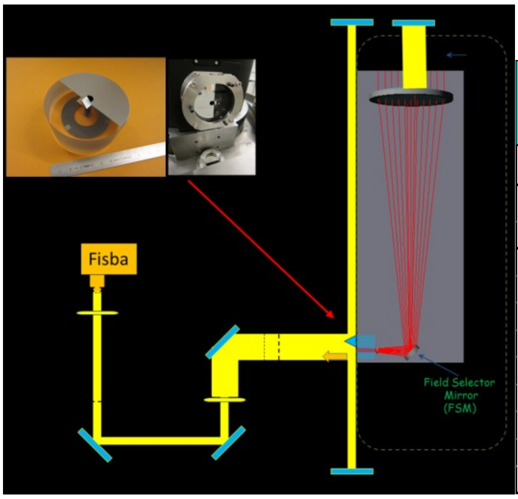


Figure 6: Left: picture of LTS on tilt stand, with 2D scanning stage at OTA output. Right: polarization measured at OTA output, at full laser power. The 2D plots show the measured Stokes component ratio S3/S0 (left) and ellipticity angle χ at 58° tilt angle (measurement run 76). The criterion of (<S3/ S0>) > 0.82, is met in all cases that we observed under operational loads. The launch telescope throughput (from laser output to OTA output) is measured >92 %.



Repeatability OTA vs Baseplate							
	C1 ALT			C2 AZ			
Zenith	ΔC1 (arcsec)			ΔC2 (arcsec)			Zenith
[deg]	15C	10C	1C	15C	10C	1C	[deg]
-60	3.2	7.6	4.3	0.8	2.6	1.9	-60
-45	3.2	9.3	5.1	0.8	2.7	2.0	-45
-30	3.6	8.8	5.6	1.0	3.1	1.9	-30
-15	4.0	5.6	5.8	1.3	2.9	1.7	-15
0	2.6	6.4	9.8	1.6	3.1	3.4	0
15	2.4	3.4	8.2	2.8	0.9	0.9	15
30	1.2	2.5	7.9	1.8	0.6	0.9	30
45	1.9	3.9	8.7	1.8	0.9	3.1	45
60	1.6	1.3	6.3	1.7	0.9	0.6	60

Figure 7: Left: sketch of LTS output beam pointing reproducibility test setup with picture of interferometer probe beam splitting device (see also [6]). Right: LTS1 pointing repeatability max. error for different temperatures and tilts, measured in the laboratory. The launch telescope optical axis pointing stability, or repeatability error, has to be within ±2.5" on-sky. This triggered the request of an additional Ø15-cm aperture Laser Pointing Camera (LPC), piggybacked on the UT4 Topring. For every new UT4 preset, the LPC determines the LGS pointing offset corrections during AO idle time. The LPC gives also LGS return flux and fwhm, and monitor the uplink scattering. The LPC was built under ESO specifications by the INAF Osservatorio Astronomico di Roma.

3. LGSU#1 STAND-ALONE COMMISSIONING RESULTS

After its shipment readiness review, the LGSU#1 together with the local control computers, safety interlock system and laser system heat exchanger was installed at UT4. Following functional verification tests during day-time incl. EMC verification, LGSU#1 was commissioned stand-alone in two runs of 14 nights total duration. A first cut on the achieved key performance tests results are presented in Figure 8 to Figure 11 below. At the time of writing the full data analysis of the LGSU#1 commissioning runs is still ongoing.

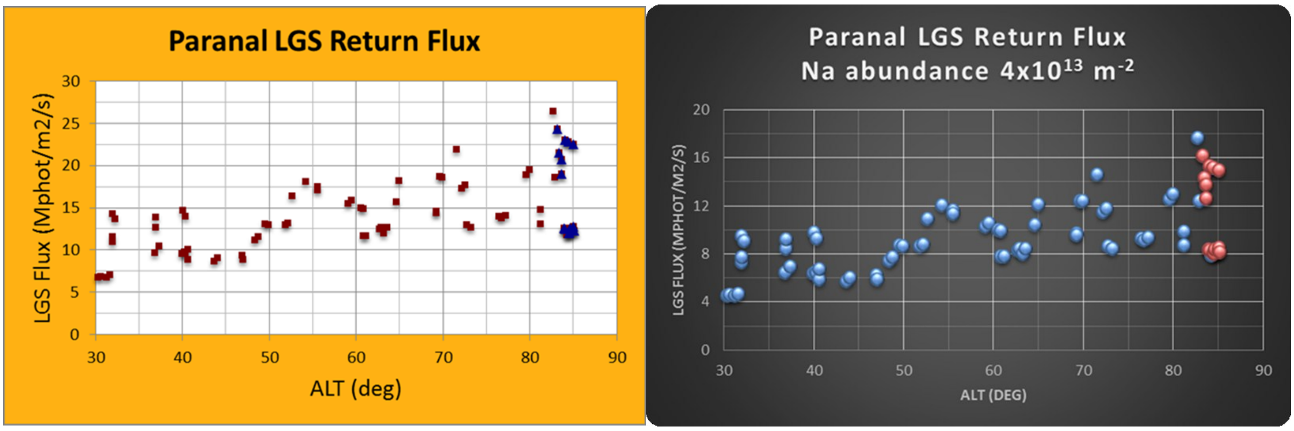


Figure 8: Left: measured LGS1 return flux during the nights of 2015 August 31st and September 1st vs UT4 ALT. The azimuth dependence is not shown here. Right: LGS1 return flux results with the sodium abundance scaled from ρ_{Na}=6x10^{13} m^{-2} to ρ_{Na}=4x10^{13} m^{-2}. Also during the commissioning nights of April and May the return flux was always measured to be above specification.

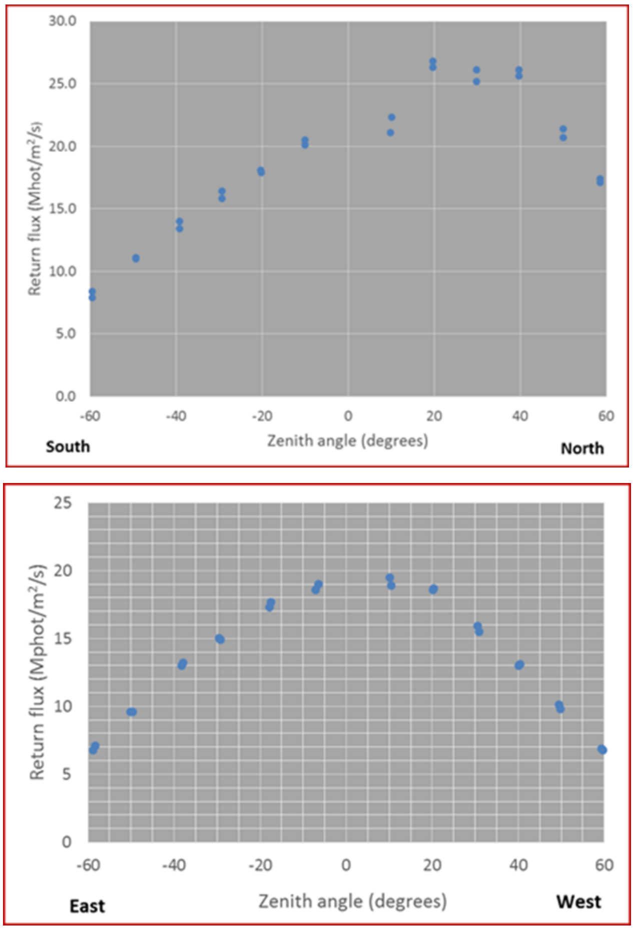


Figure 9: Measured return flux during N-S (top) and E-W (bottom) altitude scans, in the nights August 31st and September 1st. The flux varied between 7 and 26.5 Mphot/s/m^2 depending on the pointing direction. The asymmetry in the N-S scan is foreseen by the models (see e.g. [7]), and it is due to the optical pumping dependence on the direction of the geomagnetic field.

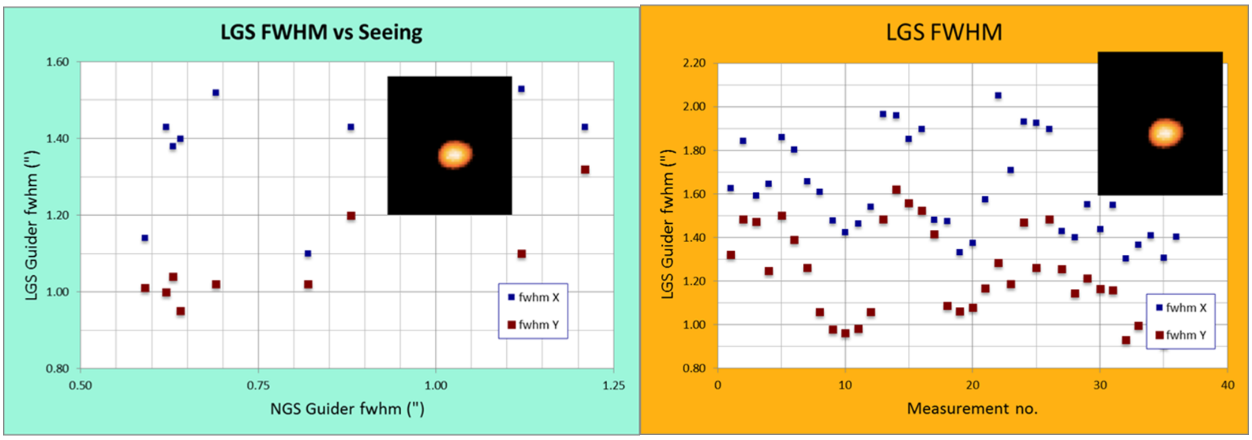


Figure 10: Left: short exposure (0.05s) FWHM averaged 10 times per point, of the LGS1 vs the NGS, taken at the UT4 guider. Right: 1sec exposures FWHM averaged 10 times per point, taken at the guider for different UT4 pointing altitudes and seeing condition. Note the variation of LGS1 elongation, likely caused by variation in the sodium layer thickness

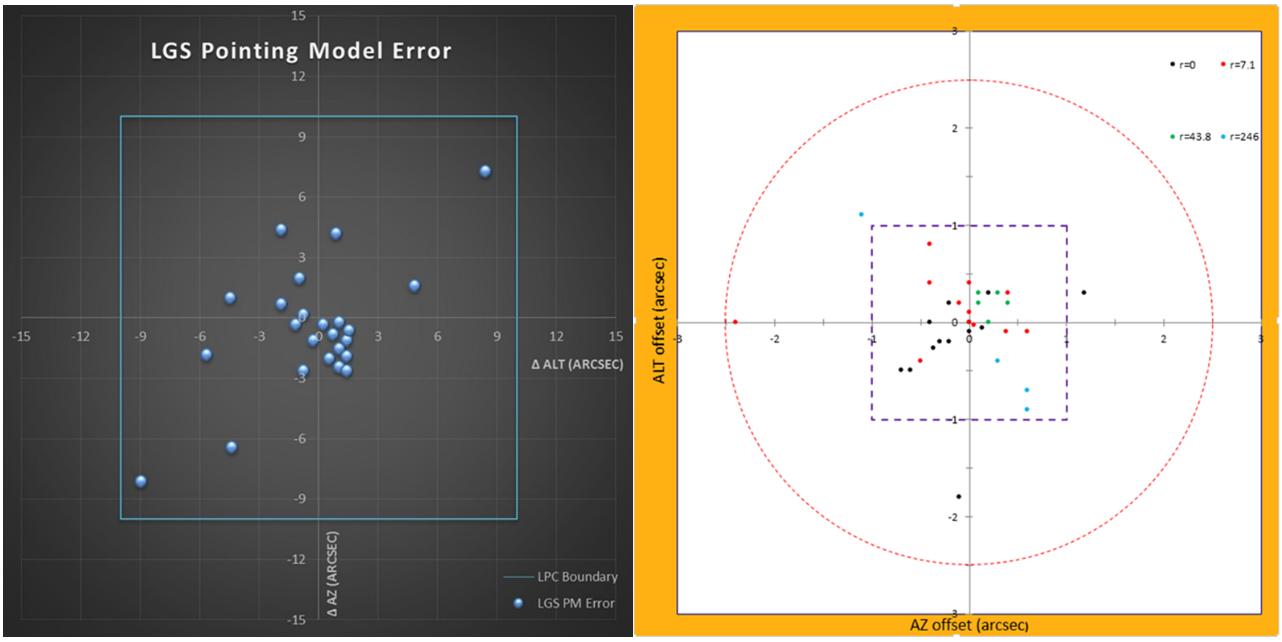


Figure 11: Left: LGS1 pointing model error as derived from the two stand-alone commissioning runs with LGSU#1. The error is within the 10" of the LPC search range for the LGS, around the nominal LGS asterism. The measurements span the 4LGSF operational range of AZ and ALT (30° to 85°). The source of error are flexures, mechanical hysteresis, calibration errors. Right: Measured LGS1 pointing accuracy. The difference between the actual LGS position and the nominal preset has been determined after applying the LPC correction, for different altitudes of UT4, and for the three asterisms of LGS1; i.e. LGS (ALT,AZ) coordinates, relative to UT4 centerfield, of (7,7)", (46,46)" and (246,246)". The red circle represents the specified open loop pointing error of 2.5" radius. The inner square is 2"x 2".

4. CONCLUSION

All 4LGSF tests are passed for the European part, and only minor follow-up actions have to be completed at the VLT. LGSU#2-4 are compliant at subsystem and system level with all requirements and interfaces and ready for deployment at Paranal Observatory. The successful stand-alone commissioning of LGSU#1 done at UT4 in advance is supporting the shipment readiness of the 4LGSF system remainder to Paranal Observatory.

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