GALACSI on the mountain: first on-sky stand-alone results

P.La Penna*[,a,], E.Aller Carpentier[a], J.Argomedo[a], R.Arsenault[a], M.Boccas[b], C.Cardenas[b], R.Chester[b], R.D.Conzelmann[a], B.Delabre[a], R.Donaldson[a], P.Duhoux[b], C.Elao[b], F.Gago[a], J.C.Guerra[b], P.Gutierrez-Cheetam[a], N.Haddad[b], P.Hagenauer[a], N.Hubin[a], S.Huber[a], P.Jolley[a], M.Kiekebusch[a], J.P.Kirchbauer[a], B.Klein[a], J.Kolb[b], H.Kuntschner[a], M.Le Louarn[a], J.L.Lizon[a], P.-Y.Madec[a], A.Manescau[a], L. Mehrgan[a], V. Nurzia[b], S.Oberti[a], M.Pozzobon[b], J.Quentin[a], C.Ramirez[b], F.Salgado[b], S.Sanhueza[b], B.Sedghi[a], F.Selman[b], W.Siclari[b], C.Soenke[a], S.Stroebele[a], M.Suárez Valles[a], M .Tapia[b], S.Tordo[a], J.Valenzuela[b], J.Vernet[a]

[a]European Southern Observatory; Karl-Schwarzschild-Strasse 2; D-85748 Garching; Germany, [b]European Southern Observatory; Paranal Observatory; Chile

ABSTRACT

After an exhaustive test period in Europe, GALACSI, the AO module for MUSE, was shipped to Paranal and installed on the UT4 VLT telescope in March 2017. We are reporting here about the status of the integration of the GALACSI module on the telescope, a summary of the stand-alone performance will be detailed, as well as the coupling with MUSE and the first IRLOS (InfraRed Low Order Sensor) images.

Keywords: Adaptive Optics, AOF, GLAO, LTAO, MUSE, Sodium Laser Guide Star, Deformable Secondary Mirror.

1. INTRODUCTION

GALACSI was developed in the frame of the Adaptive Optics Facility AOF [1]. It was mounted in March 2017 on the Nasmyth platform B of VLT UT4, to provide to MUSE an AO corrected wavefront in the MUSE [2] wavelength observation range (between 465 and 930 nm) acting on the UT4 Deformable Adaptive Mirror (DSM) [3].

GALACSI is fully described in [4]. In its first operational modes, the Wide Field Mode (WFM) [5], the goal requirement is to increase the ensquared energy within a MUSE spatial pixel of 0.2”×0.2” by a factor 2 at 750nm and for seeing conditions from 0.6” to 1.1” by means of ground layer correction. For the Tip-Tilt (TT) is used a reference star of magnitude 17.5 or brighter located outside the scientific FoV of MUSE . Sky coverage larger than 80% at the galactic pole is achieved thanks to four Laser Guide Stars (LGS), also located outside the MUSE field of view, at 64”. AO correction works therefore in the GLAO scheme. In the other mode, the Narrow Field Mode (NFM) [5] the goal is to provide Strehl Ratio (SR) ≥5% at 650 nm for 0.6” seeing with a Near Infrared (NIR) TT source of magnitude 15 in J-H band. In this mode, four LGS at 10” off axis are used, outside the NFM FoV of MUSE (a square of 7.5” side). With close LGS the whole turbulence around the telescope axis is probed, and the best wavefront error estimate and correction is performed through LTAO [6] algorithms. To attain the required SR, the Tip-Tilt Star (TTS) must be close to the telescope axis, which means in the MUSE FoV. In order not to reduce the throughput to MUSE, a dedicated TT sensor (IRLOS, InfraRed Low Order Sensor), that gets only Near Infra-Red (NIR) light separated by a dichroic after the MUSE derotator, is attached for this purpose below the MUSE Fore Optics.
After reintegration and internal functional tests at Paranal, using only the GALACSI internal calibration unit, the module was installed on the Nasmyth platform, aligned with respect to MUSE and verified on sky, before starting closing the loops with the DSM.

2. INTEGRATION AT PARANAL

After the testing phase in Europe between 2015-16 [4] GALACSI was shipped to Paranal at the end of 2016. In January 2017 the system was first reintegrated in the Paranal integration hall on a dedicated test stand. The reintegration included:

- Reassembling of the whole structure, including IRLOS.
- Electrical and cooling connections.
- Realignment of the optics using the internal Calibration Unit.
- Check of the alignment.
- Functional tests of all the actuators.
- Software verification (Instrument Control Software, data acquisition, RTC…).
- Field Selector tracking.
- Technical templates verification.

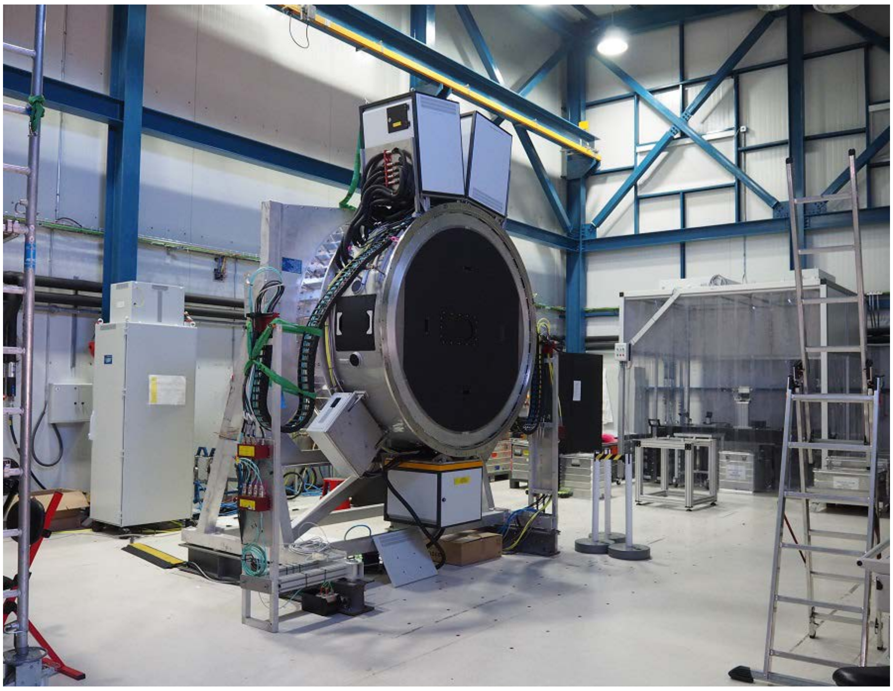

Figure 1: GALACSI reassembled and tested in standalone in the Paranal Integration Hall, at end of January 2017.

The system reintegrated and tested in standalone was then ready to be transported to the platform.

3. INTEGRATION ON THE VLT UT4 NASMYTH B PLATFORM

After preparation of the telescope platform (electrical, cooling, optical fibers connections, external electronics and RTC cabinets) the whole integrated module was transported to the telescope in March 2017.
The module was transported mounted on its test stand with a dedicated truck. The full weight of GALACSI, including the electronics cabinets attached to the module, is over 1200 kg, over 1400 kg including the test stand. To cover the distance of 3 km between the integration hall and the telescope the truck took over half an hour.

The module was introduced in the UT4 through its loading hatch, and, after disconnecting it from the test stand, lifted with the dome crane up to the telescope platform, using a dedicated balanced crane tool. The whole operation, including transport, entering the telescope and lifting to the platform, required over half a day of work.

Figure 2: Left: GALACSI, mounted on its test stand, on the transport truck from the integration hall and the telescope. Right: the GALACSI module lifted by the dome crane and the balanced tool at the height of the telescope platform.

Owing to the limited space, the insertion of GALACSI between the telescope adapter and MUSE on the platform was a particularly critical operation. Between GALACSI and the MUSE Fore Optics (including the derotator and the MUSE calibration unit) there are less than 3 mm of free space. In order to allow the insertion of GALACSI it was necessary to first remove the MUSE calibration unit and to install a temporary protection tool, to avoid that possible oscillations of the module during lowering it down could let GALACSI hit the instrument structure. Reference pins allowed to guide the attachment of the GALACSI interface flange to the adapter-rotator one, to reproduce the correct orientation. Even with this precaution, sliding GALACSI between the telescope and MUSE and fixing it to the adapter-rotator flange was a very delicate operation, which required the remaining half day. At the end of the day GALACSI was installed on the platform, attached on the adapter-rotator flange, the temporary transport and protection tools were removed and the MUSE calibration unit had been reinstalled.

Figure 3: Left: GALACSI is being transported toward the telescope adapter. The available space is the one between the telescope adapter/rotator and the yellow tool, protecting the structure of MUSE. Right: GALACSI attached to the telescope adapter/rotator, inserted in its position, between the telescope and MUSE.

4. GALACSI VERIFICATION ON THE PLATFORM

4.1 Lateral alignment GALACSI-MUSE

Aligning GALACSI with respect of MUSE means to overlap the optical axis of GALACSI, defined in the standalone alignment with its internal Calibration Unit, with the optical axis of MUSE and the one of the telescope and telescope adapter/rotator. A poor alignment would significantly affect MUSE and AO performances, in particular in GALACSI NFM. Obtaining this alignment required a critical tuning.
Usually an instrument is mounted and aligned with respect of the telescope beam. Aligning with great accuracy an additional instrument (or module) on an already aligned instrument axis on the telescope is something unconventional. In an ideal alignment of the systems on Nasmyth platform B of UT4, all the following axis should be overlapped:

1) Telescope altitude axis
2) Nasmyth adapter axis
3) Nasmyth rotator axis
4) MUSE derotator axis (minimum wobble on MUSE detector when rotating the derotator)
5) GALAXI axis (axis of the internal alignment of GALACSI

MUSE had been aligned before the installation of GALACSI on the telescope, its axis, defined by the MUSE derotator axis (reference pixel, the one with minimum wobble when rotating the derotator), being superposed with the telescope adapter/rotator axis and with the telescope altitude axis.

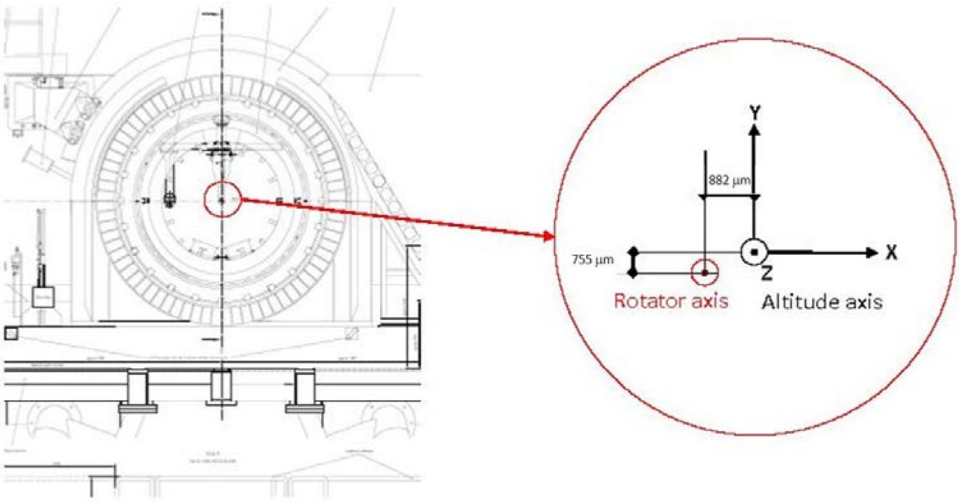

Figure 4: Expected amount and direction of the off-centering between adapter/rotator and MUSE derotator axis, according to the measurements performed with GALACSI CU and MUSE in NFM. The Altitude Axis is aligned with the MUSE derotator axis.

GALACSI was then mechanically centered with respect to the telescope adapter/rotator axis.
However, after the first verifications, the axis of the Nasmyth B adapter/rotator on which GALACSI was mounted resulted shifted with respect to the MUSE derotator axis. This was a consequence of an adapter/rotator corrective intervention previous to the installation of GALACSI. GALACSI itself was quite close to the adapter/rotator axis (within 1” equivalent on-sky), but, since this last axis had a lateral offset to the MUSE one, GALACSI resulted misaligned with respect to the MUSE axis by an amount about 3” on-sky, which would result in degraded performances, in particular in NFM, a degradation of the MUSE functionalities due to the guider arm offset wrt MUSE and vignetting of the MUSE field of view by GALACSI.

We could deduce from the difference in position of the GALACSI CU between the matching of the rotator center and the one matching the derotator center, that in order to put back the rotator axis on the MUSE derotator axis, the movement should have been in the direction shown in Figure 4 (looking from MUSE into the telescope): about 750 μm upwards and 880 μm rightwards). It was therefore necessary to correct the off-centering.
To improve the alignment without dismounting again GALACSI from the adapter/rotator, it was decided to perform an operation not tried before:

1) Support the entire block adapter+rotator+GALACSI with crane and hydraulic jack.
2) Release the screws fixing the adapter to the telescope, without removing them.
3) Push with push-pull screws in the identified direction.

As a monitoring for the displacement:

1) The on-axis source (9 μm diameter) of the GALACSI CU was imaged on the MUSE NFM detector.
2) The source was positioned in the previously identified GALACSI CU position corresponding to the rotator axis.
3) The MUSE derotator is set on 0 degrees (for the final result it makes not significant difference in which position it is).
4) The block adapter+rotator+GALACSI was shifted until the CU spot reached the MUSE NFM reference pixel.
5) Four position gauges were mounted on the horizontal and vertical axis off the adapter to monitor in real time the mechanical displacement.
6) An additional position gauge was monitoring the tilt (when releasing the screws the weight of GALACSI made the entire block incline in direction of MUSE).

The screws were released by something of the order of one mm, in order not to let the adapter shims fall and not to incline. The operation was considered successful if:

- With the position the GALACSI CU fiber on the rotator center position (CUx=14.831 mm; CUy=13.0688 mm),
- The GALACSI CU spot had moved to the MUSE NFM reference pixel (X=160, Y=155),
- with an accuracy better than 250 μm on the Nasmyth plane (±9 pixels on the MUSE detector).

Before starting, the GALACSI CU was positioned at the nominal rotator axis position:

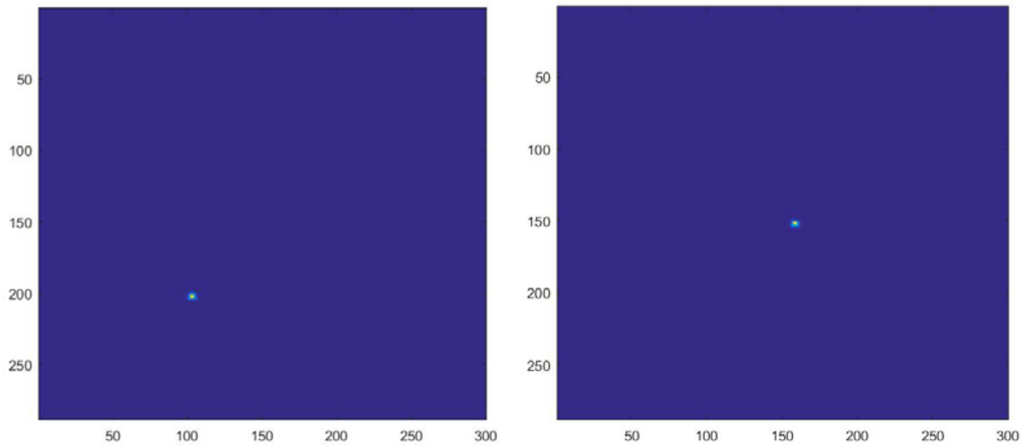

Figure 5: Left: position of the spot before starting the adapter+rotator+GALACSI shift; right: at the end of the intervention. The whole shift was more than 1 mm, corresponding to about 1.9" on sky.

The operation went on by gradually releasing the almost 200 screws fixing the adapter/rotator to the telescope flange. This procedure took 2.5 hours, until the adapter/rotator was released from the telescope. At this point the push-pull on the whole block GALACSI+adapter/rotator could start. The shift was completed within the next half an hour. At this point the screws were tightened again. When the crane and the supporting jack were removed, no movement of the spot on MUSE was detected.

The total displacement with respect to the initial position was been very close to the expected one:

$\Delta X_{nasmyth}$ = 55.5 pixel (1.39” = 816 μm)
$\Delta Y_{nasmyth}$ = 50.0 pixel (1.25” = 736 μm)
$\Delta_{total-nasmyth}$= 70.3 pixel (1.86” = 1.09 mm)

As a result of the intervention, the axis of GALACSI was about 1” from the telescope rotator axis, much closer to the MUSE one than before the intervention (about 3”).

4.2 Check of the vignetting

The results of this realignment were checked on-sky. Before the realignment we had measured some vignetting for some GALACSI rotator positions (-45 degrees) and MUSE derotator in MUSE WFM. This vignetting was cleary produced by the offset of GALACSI wrt MUSE.
In the test performed with twilight after the realignment, for all the MUSE derotator positions, at the same GALACSI derotator position (namely -45 degrees) the vignetting had fully disappeared (Figure 6, left).

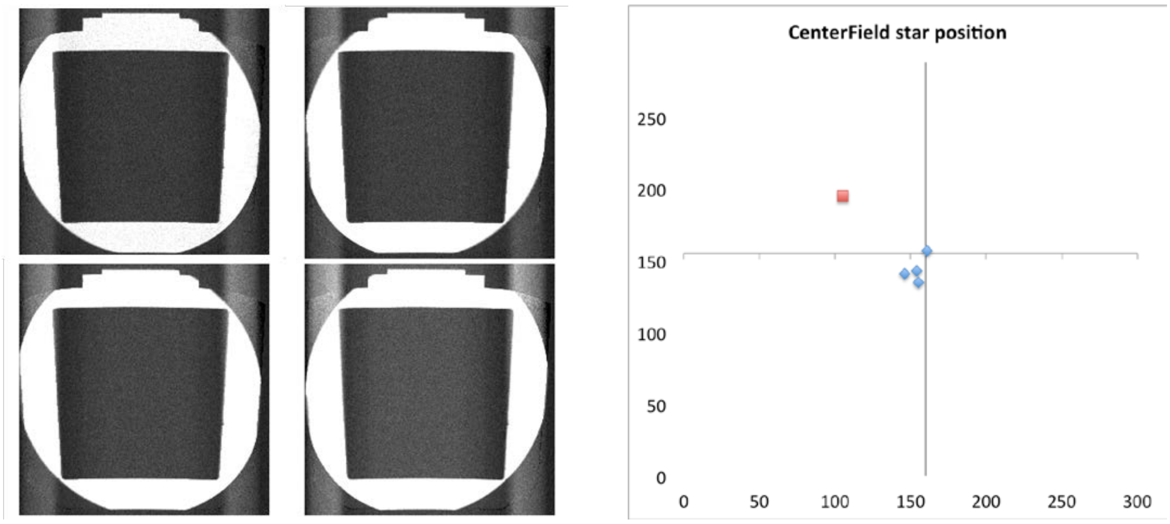

Figure 6: Left: MUSE Slow Guiding System for 4 positions of the MUSE derotator (0 90, 180, 270) at a telescope rotator angle of -45 (corresponding to the position during observations at zenith). Before the intervention it was the position where the most important vignetting was occuring. This now shows that there was no longer vignetting of the MUSE science field of view (central dark square) by GALACSI annular mirror (the ellipse). Right: Red: position of a star on the adapter center measured on the MUSE detector in NFM before the shifting intervention. Blue: distribution of the adapter center (still MUSE NFM) after the shift of adapter+rotator+GALACSI. The axis crossing is the MUSE NFM reference pixel (x=160; y=155). The centroid of the distribution is at about 300 mas from the reference pixel (it was about 2 asec before).

4.3 Measurement of the adapter center field

A star was centered at the CenterField position. This measurement was repeated on the same star for 4 different positions angle of the Adaptor separated by 90 degrees. At each position data were recorded and measurements of the centroid were done on the Fast reconstructed images in R band.
Results are shown in blue in Figure 6 (right). Axis cross at the reference position of the MUSE derotator axis (160,155). The red dot shows the measurement done before the correction of the Adaptor/Rotator (ESO-300165), blue dots the points measured after the intervention. The centroid of the distribution is now about 300 mas from the MUSE NFM reference pixel, to be compared to the previous 2 arcsec. The residual offset between adapter center and MUSE derotator could be due to a residual off-centering between the adapter and the telescope rotator.

4.4 Guiding

The same test of the slow guiding at the meridian crossing, as performed on the 29th March (ESO-300165), was also performed in the night 27-28 April. The slow guiding correction sent to the adapter was recorded for 20 min around the zenith passage. Before the activity on the Nasmyth B motor and the GALACSI installation the correction was within ±0.1 asec. After the GALACSI installation it had increased significantly, owing to the misalignment between the telescope adapter and the MUSE derotator axis. After the realignment of the adapter+rotator the situation has recovered, coming back to the situation previous March 2017.

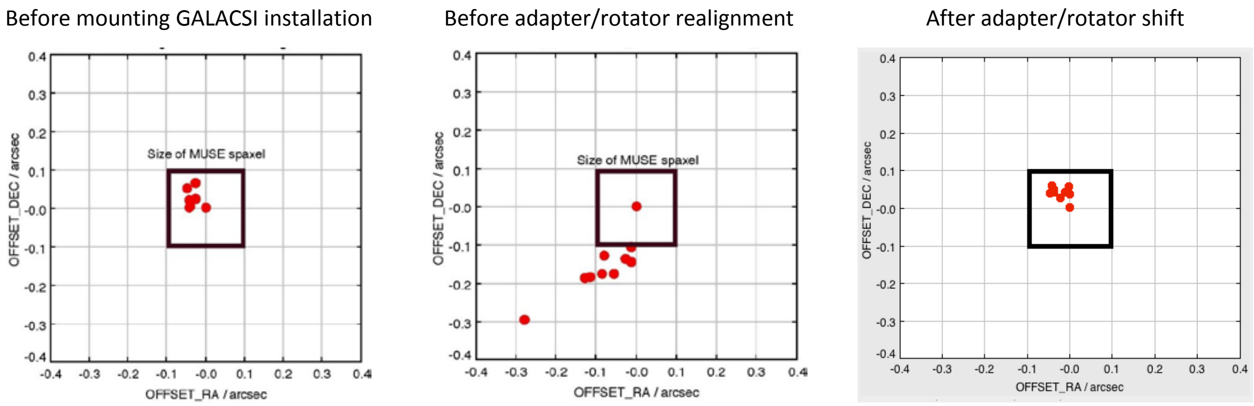

Figure 7: Slow guiding correction around zenith: top plot: before the Nasmyth B motor intervention of begin of March. Center: March 2017, after an activity on the adapter/rotator and GALACSI installation. Bottom: night of 27-28 April. The amplitude of the correction is back to the normal situation.

4.5 MUSE versus GALACSI axial focal plane position

MUSE was positioned and aligned to have its input focus superposed to the VLT Nasmyth focus. Also the focus of GALACSI, with respect to which its internal optics had been aligned, must be overlapped to this focus.

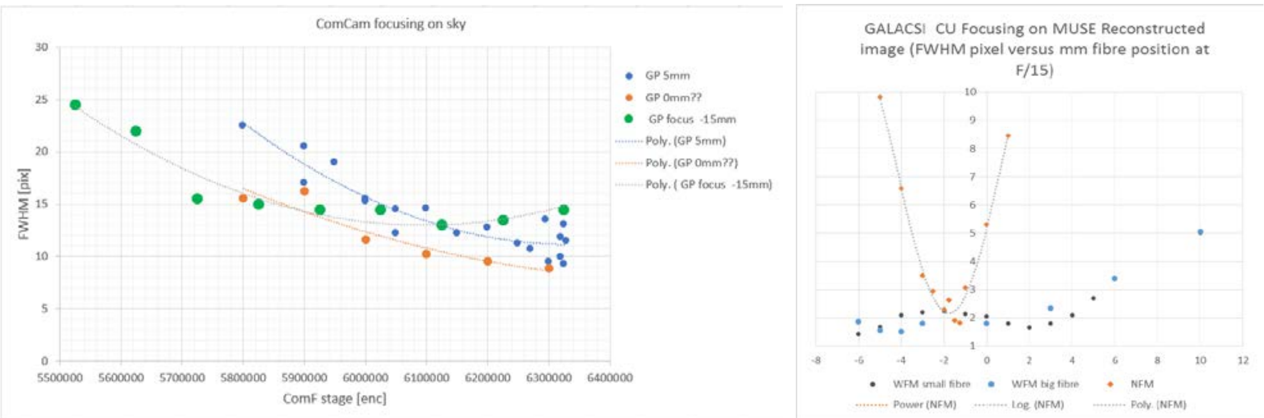

Figure 8: Left: NGS focused on the GALACSI Commissioning Camera. The different spots are taken with different positions of the focusing lens of the Commissioning Camera: the focused position corresponds to the minimum spot dimension. The difference in actuator position on-sky with respect to the standalone alignment was about 5 mm in the direction of the telescope. On the right a similar measurement is performed focusing the GALACSI Calibration Unit on MUSE: the GALACSI focus should correspond to the value 0. Both in WFM and NFM there is a shift of the minimum, not clearly identified in WFM, but consistent with about -5 mm with respect to the expected position. In NFM this value is better identified and smaller (about -2 mm).

To verify this, a NGS was acquired and focused on the GALACSI Commissioning Camera, using the focusing actuators of GALACSI. This first check (Figure 8, left) already showed that GALACSI was about 5 mm too far from the correct focus position.
A similar measurement was performed checking the best focus position of the GALACSI Calibration Unit spot on MUSE: also in this case (Figure 8, right), the best focus position is not clearly identified in WFM, but it appears shifted by several mm with respect to the expected position. In MUSE NFM is more clearly shifted by -2 mm. This focus shift has consequences mainly on the spot dimension on the GALACSI TT sensor: if not fully focused, the larger spot results in a lower flux per pixel, thus driving to a loss in maximum accessible magnitude and reduced sky coverage.
In order to fix this problem, we removed a shim of about 300 μm from the TT wavefront sensor mount. This allowed to recover a focused spot on that detector.

4.1 Tip-tilt and Field Selector on-sky

Functional on-sky verification and tuning of the TT pointing model and tracking is performed before closing the AO loops on the DSM. The procedure requires the identification of a suited NGS, telescope tracking and execution of the Field Selector (FS) pointing model. The pointing model is the open loop movement of the FS mirror which allows to keep the TT NGS star, which is not on axis in GALACSI WFM, centered on the reference pixel of the Visible TT WFS. The star is then imaged on the GALACSI Commissioning Camera, and its drift there gives the measure of the accuracy of the TT tracking.

In Figure 9 the result of the tuning and verification on-sky is shown, for several stars in the NGS TT field of view of GALACSI (defined by the area of the GALACSI annular mirror placed on the VLT Nasmyth plan). With the exception of Star #4 (placed at the very edge of the accessible field) all drift are within the specifications (150 mas over 1 h exposition).

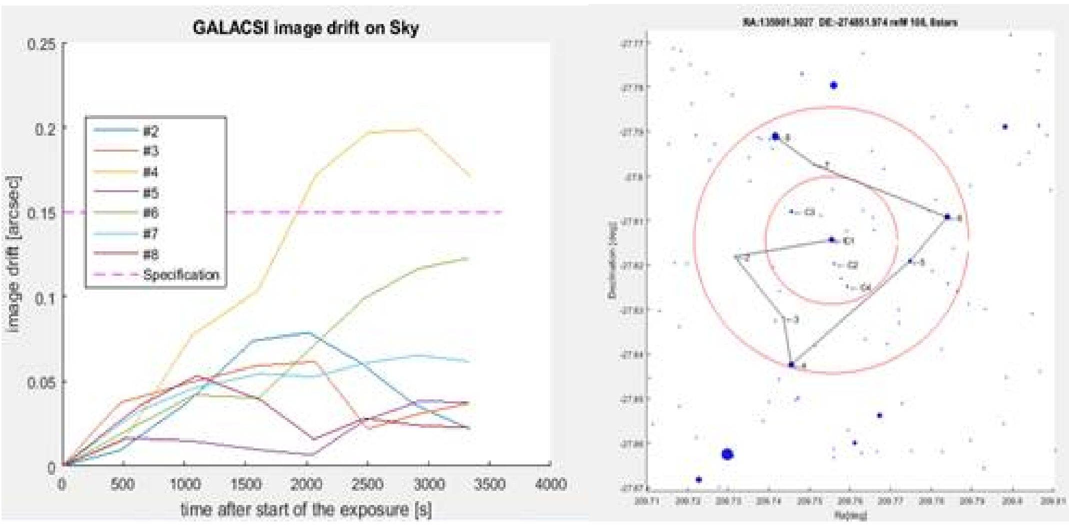

Figure 9: TT control: drift measured on the Commissioning Camera during a meridian passage 3 deg. off Zenith (for 7 different TT stars covering the FS field).

4.2 LGS acquisition

The first acquisition of the four Laser Guide Stars (LGS) on sky required some effort. GALACSI is designed and aligned to center four LGS on four LGS wavefront sensors (WFS). In WFM the LGS stars are on a circle having a diameter of 128” (20” in NFM). The range of acquisition of the LGS-WFS (the field of a subaperture of the LGS Shack-Hartmann) is 5”. The full final procedure to acquire the LGS star optimization is described in another contribution to this conference [10]. The first time we performed it, it took several hours to find the stars. At the end we were able to image correctly the telescope pupil on the four LGS-WFS (Figure 10). It was however already sufficient to check the correct conjugation and alignment with the LGS on sky, the correct dimension of the pupil on the LGS-WFS lenslet array (5.7 mm) and the focus tracking of the LGS distance with the change of the telescope altitude angle.

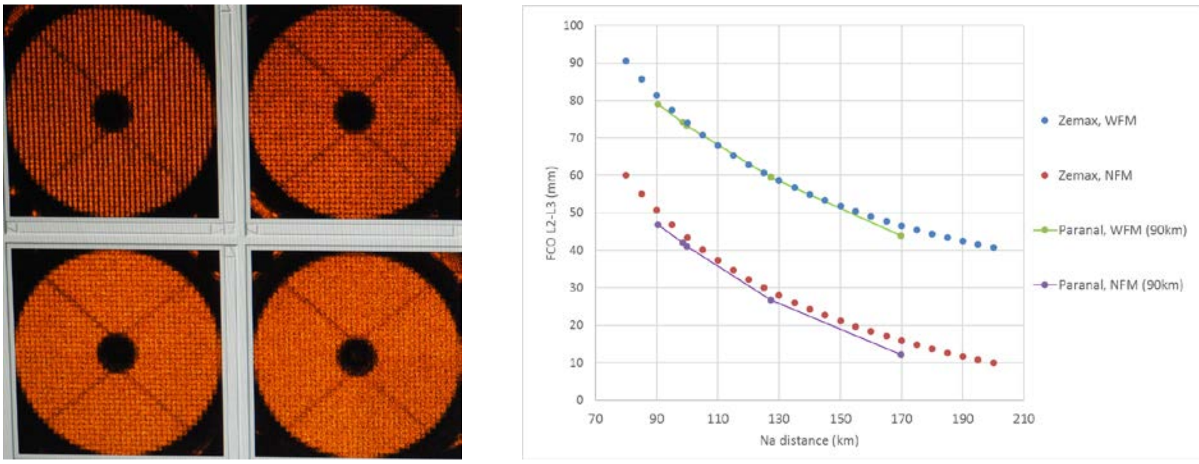

Figure 10: Left: first acquisition of the four LGS on the four LGS Wafefront sensor of GALACSI. The first acquisition took several hours. After optimization it takes now a couple of minutes. Right: focusing the LGS on the LGS-WFS changing the focusing stage (Focus Compensating unit, FCO), when changing the telescope altitude. The plot of that night reproduced well the design expectations, if the LGS layer zenith altitude was the realistic value of 90 km.

4.3 IRLOS

IRLOS resulted immediately close to a good alignment on-sky: the spot of the 2×2 lenslet array were pretty well centered on the four detector windows. But even in its Large Scale configuration, with four windows of 20×20 pixels and pixel scale of 250 mas/pixel (5 asec/subaperture), the spot dimension and the residual TT fluctuation don't allow to characterize further the quality of the IRLOS alignment. This can be done only once the LTAO loops will be closed in GALACSI NFM. However, already after the first acquisition of the LGS on the LGS-WFS it was possible to close a GLAO loop in a first adaptive optics correction. This allowed stabilize and reduce the spot dimension, in a sufficient way to check an image on the IRLOS detector. The light spot can be detected in a configuration where IRLOS has no lenslet array and a single spot is focused on the detector. In this configuration the entire window is 280×280 pixels, with a pixel scale of 7.5 mas/pixel. Closing the GLAO loop resulted soon in a spot size reduction of a factor larger than 2 (Figure 11).

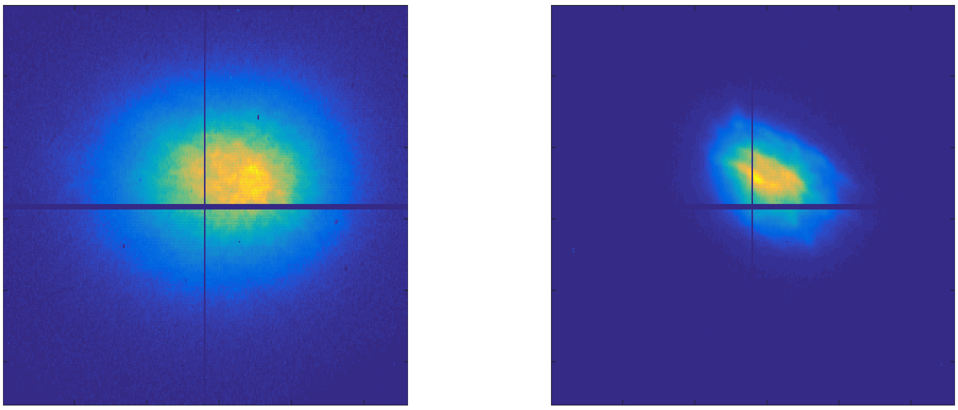

Figure 11: IRLOS PSF image (wavelength range: 950-1800 nm): (Units: pix: 1 pix=7.5 mas). Left: seeing limited. Right: GLAO closed loop.

5. CONCLUSION

GALACSI was successfully installed on the VLT UT4 Nasmyth B platform in March 2017. The alignment with MUSE and on-sky was soon verified, allowing starting with the commissioning phase in which the full adaptive optics performances with MUSE could be tested. The fast and successful installation on the telescope was the result of an intense work during the installation itself, but also of a careful preparation in the years before. Extensive testing of GALACSI and of all the other components of the AOF in Europe, first in standalone and then on the ASSIST test facility with the DSM [8] [9] have allowed to respect the installation schedule and save significant telescope time.

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