ASSIST : The test set-up for VLT Adaptive Optics Facility

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Plan of the talk

- VLT
- Adaptive optics
- AOF – The Adaptive Optics Facility for VLT
- AOF → ASSIST
- Requirements of ASSIST
- Different modes of ASSIST
- Optical Design
- Mechanical Design
- Current status
The Very Large Telescope (VLT) is the flagship facility for European ground-based astronomy. It consists of four Unit Telescopes with main mirrors of 8.2m diameter and four movable 1.8m diameter Auxiliary Telescopes.

The telescopes can work together, in groups of two or three, to form a giant 'interferometer', the ESO Very Large Telescope Interferometer.

The 8.2m diameter Unit Telescopes can also be used individually. With one such telescope, images of celestial objects as faint as magnitude 30 can be obtained in a one-hour exposure.

The VLT has stimulated a new age of discoveries, with several notable scientific firsts, including the first image of an extrasolar planet, tracking individual stars moving around the supermassive black hole at the centre of the Milky Way, and observing the afterglow of the furthest known Gamma-Ray Burst.
VLT: Instrumentation

- FORS1 (FOcal Reducer and Spectrograph) and its twin, FORS2, can be used for imaging in the visible and for low-resolution spectroscopy.
- ISAAC (Infrared Spectrometer And Array Camera) is an infrared imager and spectrometer, observing in the 1 to 5 µm range.
- UVES (Ultra-violet and Visible Echelle Spectrograph) is the high-dispersion spectrograph of the VLT, observing from 300 -1100 nm, with a maximum spectral resolution of 110 000.
- NACO is an Adaptive Optics facility producing images as sharp as if taken in space.
- VIMOS (VIsible Multi-Object Spectrograph), a four-channel multiobject spectrograph and imager, allows obtaining low-resolution spectra of up to 1000 galaxies at a time.
- FLAMES(Fibre Large Array Multi-Element Spectrograph) is capable to study simultaneously and at high spectral resolution hundreds of individual stars in nearby galaxies.
- VISIR (VLT Imager and Spectrometer for the mid-InfraRed) provides diffraction-limited imaging at high sensitivity in the two mid infrared (MIR) atmospheric windows (8 to 13 µm and 16.5 to 24.5 µm).
- SINFONI is a near-infrared (1 - 2.5 µm) integral field spectrograph fed by an adaptive optics module.
- CRIRES (CRyogenic high-resolution InfraRed Echelle Spectrograph) provides a resolving power of up to 100 000 in the spectral range from 1 to 5 µm.
- HAWK-I (High Acuity Wide field K-band Imager) is a near-infrared imager with a relatively large field of view.
- X-shooter (a wide-band [UV to near infrared] spectrograph) is designed to explore the properties of rare, unusual or unidentified sources.
Adaptive Optics
Adaptive Optics…

• We need lot of optics for adaptive optics to re-image pupil on deformable mirror. j20
• “Post-focal” AO systems add an optical train of 5 to 6 warm mirrors for the pupil imaging and the DM.
• The alternative is to make one mirror of the telescope train being adaptive. The whole telescope becomes then an adaptive optical system offering fast wave front correction without the addition of supplementary optics or mechanics. j21
This reduces the throughput, increases scattering and thermal emissivity, limits the maximum FoV to <3' and it occupies a significant part of the volume, mass and power budget available for Instruments.

Moreover, with the 2 Nasmyth and Cassegrain focii this gain can be threefold. The DSM allows the use of the full VLT FoV without the additional hardware cost and development and maintenance efforts of the post-focal systems. As a completely new M2 unit is developed, the existing one can be used as a spare part for the remaining 3 UTs.

For example, due to its large FoV of 10' it would be not possible to implement a post-focal AO system for HAWK-I.
The Adaptive Optics Facility is a project to convert one VLT-UT (Unit Telescope) into a specialized Adaptive Telescope.

The present secondary mirror (M2) will be replaced by a new M2-Unit hosting a 1170 actuators deformable mirror.
Why do we want to do that? Adaptive Optics (AO) systems are becoming common place for the next generation of instruments. Common in these modern AO systems is the Deformable Mirror (DM) and although the development of DMs has led to many new and innovative concepts, the DM remains one of the more expensive components. At the same time, the DM is the only component that is required to be in the science path. Since operating in the pupil plane, several optical elements are required for pupil re-imaging and will lead to a decrease in throughput of the system and in the case of thermal infrared to an increase in emission. At the same time, the DM is the only component that is required to be in the science path. Since operating in the pupil plane, several optical elements are required for pupil re-imaging and will lead to a decrease in throughput of the system and in the case of thermal infrared to an increase in emission. Many of these problems associated with the DM can be mitigated by making one of the existing elements in the telescope deformable: Since the DM is part of the telescope all instruments on this telescope can make use of it and since it is replacing an existing component of the telescope no additional loses in throughput or increase in emission are to be expected.

jolissaint, 11/17/2008
• 4LGF: using sodium fiber lasers and 4 Launch Telescopes on the UT centerpiece.
• SPARTA: a flexible Real-Time-Computer Platform providing the computational power for the real time control for several AO systems.
• ASSIST: a complete Test Facility allowing complete testing & characterization of the DSM with the AO modules in Europe.
Laser Guide Stars are essential for the AOF to achieve the requested performance and the high sky coverage. Four (4) LGSs are required for the type of corrections needed; it is envisioned to perform Ground Layer Adaptive Optics for Hawk-I and MUSE involving averaging turbulence measurements in 4 different directions around the field of view [7] and Laser Tomography where the WF is sensed around the object but the correction calculated for the line of sight.

jolissaint, 1/6/2009
• The 3 focal stations will be equipped with instruments adapted to the new capability of this UT.
• Two instruments are in development for the 2 Nasmyth foci: HAWK-I with its AO module GRAAL allowing a Ground Layer Adaptive Optics correction and MUSE with GALACSI for GLAO correction and Laser Tomography Adaptive Optics correction.
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The AO corrections to be provided are: Ground Layer Correction (GLAO) and Laser Tomography (LTAO). GLAO consists in measuring the turbulence in four different directions outside the instrument FOV and to average it in order to provide a homogeneous image improvement across the instrument FOV. The latter compensates for the laser cone effect (not sampling all the turbulence seen on the astronomical target) and optimises high Strehl correction on-axis.
HAWK-I prime science cases include deep multi-colour surveys at high z, stellar population studies in nearby galaxies, and investigations of star-forming regions in our Galaxy. These programmes critically rely on the deepest possible exposures with the highest possible spatial resolution – both of which will be improved by GRAAL. HAWK-I with GRAAL will typically reach 0.5mag deeper in J, H and K for a fixed exposure time. For high-z observations, this is equivalent to a gain of 1.26 in distance (adopting a standard cosmology). This translates in turn into ~25% more volume probed by the survey in the same time (surveys will reach z~1.2 instead of z=1 or z~3.6 instead of z~3).
• **MUSE NFM:** In recent years it has become clear that supermassive black holes (SMBHs) are intimately linked with the mass evolution of their host galaxies and are therefore key ingredients of the formation and evolution of galaxies. The SMBHs formation processes should leave signatures in their immediate environment either in terms of stellar orbital structure or chemical enrichment history. These key issues can only be fully addressed with optical IFU observations at near-diffraction-limited resolution.

• **MUSE WFM:** The main target of the MUSE surveys is to find and study the building blocks of the local, normal galaxies such as our Milky Way, at an epoch when the Universe was typically 1 Gyr old. The observation of such objects will be of great value to clarify the way galaxies form. The benefit of AO correction is obvious since these sources are typically 0.1–0.3” in size.
Why ASSIST?

- The implementation of a DSM on the VLT raises a number of questions regarding calibration and testing. The only test sources available are natural stars and all direct testing and calibration needs to be done on-sky, taking away large fraction of time from science operations.
- Testing the DSM is challenging by itself. The DSM is a convex, hyperbolic mirror of 1.1 meter diameter and a radius of curvature of 4.6 meter. A test setup generally involves either large optics and/or long path lengths.
- The last question is how to test the AO systems for instruments for the adaptive VLT before they are brought to the telescope. Without the DSM, the AO system is not complete and only a limited number of system tests can be performed.
- Simulate VLT in lab → ASSIST.
Two DSMs have up to now been built. The first DSM has been implemented on the MMT [Hinz, 2006]. This 64 centimetre convex mirror with 336 actuators has been tested using a large lens in front of the DSM, but since the DSM for the VLT is twice as large producing the test lens is significantly more complicated and the setup required for testing would also be much larger. The second DSM is currently being implemented on the LBT [Martin, 2006]. Since the LBT is a Gregorian telescope, the DSM is a concave 0.91 m, 672 actuator elliptical mirror. Testing this mirror does not require special optical components, but the total size of the setup is still considerable.

jolissaint, 12/9/2008

Using either Hadamar matrices or low-amplitude sinusoidal modulation on top of the [Esposito, 2006] it is possible to get close to the ideal open-loop calibration, but still, the calibration is time consuming.

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ASSIST: introduction

• ASSIST (The Adaptive Secondary Set-up and Instrument STimulator) is the test set-up for the verification and calibration of three elements of the VLT Adaptive Optics Facility (AOF).

1. Deformable Secondary Mirror (DSM)
2. The AO system for MUSE (Multi-Unit Spectroscopic Explorer) - GALACSI (Ground Atmospheric Layer Adaptive Corrector for Spectroscopic Imaging)
3. AO system for HAWK-I (High Acuity, Wide field K-band Imaging) - GRAAL (GRound layer Adaptive optics Assisted by Lasers).
What will ASSIST do?

- ASSIST combines a compact interferometric setup for testing the DSM with a simulated telescope environment.
- It provides both an interface comparable to the telescope, as well as guide stars and a simulated atmosphere.
- Testing of AO systems in the lab.
- Also, ASSIST will provide an initial calibration that will allow faster convergence in the on-sky calibration.
The requirements on ASSIST are driven mainly by the two AO systems which are currently being developed in the context of the AO facility. GALACSI and GRAAL offer together in total three instrument modes:

- The GALACSI Wide Field Mode (WFM) and GRAAL both are operating in Ground Layer AO mode, with a limited correction, but over a larger field of view. This means that the requirements on the optical quality are not very stringent, but need to be obtained over a large field.

- The GALACSI Narrow Field Mode (NFM) only operates on a small field, but is expected to provide diffraction limited performance.
• Further requirements are derived from the instruments to be tested. These expect to be at the VLT, so ASSIST should provide an output focus that follows the optical prescription of the VLT, i.e., the output f-ratio should be f/15.2, while the exit pupil should be located at 16.942 meters in front of the focus. The LGS should be defocused due to the finite height of the Na layer. To simplify the setup, fixed height of 100 km is set for the setup.

• ASSIST should also provide a stable mechanical support for both the DSM (<1800 kg) as well as for the AO systems under test (<1500 kg). This means that ASSIST will also contain the mechanical interfaces that are on the VLT for the secondary and will mimic the Nasmyth Rotator flange.

• ASSIST will provide support for the DSM with the mirror surface aimed down. Since there will be limited space available, it is intended to keep ASSIST within a reasonable space envelope, preferably less then 4.5 meter high to fit within an available assembly area.
• ASSIST will be able to handle four modes of operation.
• One interferometric mode for testing the performance of the DSM and three instrument modes (the GALACSI NFM, the GALACSI WFM and the GRAAL mode) for testing of the AO systems GALACSI and GRAAL.
• For ASSIST the GALACSI WFM and GRAAL mode will be very similar. Both will have a FoV of 2.5 ‘ and have a freedom to position the LGS and NGS over field outside 1’x 1’. But for GRAAL a magnification will be applied using a set of periscopes at the exit of ASSIST to move the LGS and NGS sources to the appropriate distances for GRAAL.
Interferometric Mode
The approach used in ASSIST consists of testing the mirror at its centre of curvature with a double pass setup, significantly increasing the F-Number of the returning beam with respect to a hyperfocii-based setup and therefore putting less stress on the optical correction provided by the remainder of the system. The DSM setup consists of a concave 1.65-meter aspherical mirror (AM1) and a 146 mm diameter convex hyperboloid mirror (AM2). Figure 3 includes as well a plane fold mirror directing the beam towards an interferometer. The F-number of both the input and output beams is 19.53. Note that the 2 mirrors shapes are optimized for the interferometric mode as well as for the complete ASSIST setup in narrow (NFM) and wide field (WFM) modes. A simpler spherical shape for AM1 would have been enough to ensure good performance for interferometry, but prevented a good correction of the pupil imaging, a critical part of the ASSIST optical requirement, due to the amount of spherical aberration induced by a spherical AM1.

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• The complete ASSIST architecture aims at fulfilling the requirements of the ASSIST instrumentation modes.
• The design is based on a single optical train for all three instrumentation modes. This means that it provides imaging of the simulated NGS up to 2.5 arcmin for both 589 nm and 1600 nm, imaging of the simulated LGS up to 2.5 arcmin for 589 nm, including simulation of the defocus induced by the 100km Na layer altitude and pupil imaging (both pupil imaging at the nominal position of the phase screens simulating the turbulent atmosphere with respect to the DSM as well as pupil imaging between the DSM and the exit pupil of ASSIST).
• The larger field required by the testing of GRAAL will be achieved through a periscope system placed after ASSIST. This system will be designed within the GRAAL project.
As a result, ASSIST optical design consists of three optical modules:
- A star simulator and turbulence generator (SSTG) module. The stars are created using a custom-designed fibre source, while the turbulence is generated using several phase screens (PS) positioned at a pupil plane and higher conjugate altitudes. The optics provide full correction for the pupil conjugation as well as a diffraction-limited image on-axis, in order to simplify the alignment of the whole system.
- The DSM module as described in the previous section
- A VLT-focus simulator, which provides the conjugation of the DSM with the exit pupil and delivers a final image compliant with the VLT characteristics and the needs of the AO systems to be tested. The SSTG and VLT focus simulator are separated by a beamsplitter cube (BS2).

The stringent requirements on the imaging quality of both NGS and DSM pupil for 2 wavelength domains have led to the use of several glasses in the system in order to decrease chromatic effects.
ASSIST: Modular approach

- **SSTG Module**
  - SSTG Base Plate
  - SSTG Support

- **Optical Assemblies**
  - SSTG Front Group
  - NGS Injector Group
  - LGS Injector GALACSI
  - LGS Injector GRAAL
  - Alignment stages
  - Star Simulator
  - Turbulence Generator

- **DSM Module**
  - **DSM**
    - DSM Subassembly
    - DSM Hub
  - **DSM Tower**
    - DSM Tower Bottom
    - DSM Tower Middle
    - DSM Tower Top
  - AM1 Assembly
  - AM2 Assembly
  - FM1 Assembly

- **Interferometric Module**

- **VFS Module**
  - VFS Base Plate
  - VFS Support
  - Optical Assemblies
    - VL1.2 Assembly
    - VL3.4 Assembly
    - FM2 Assembly
  - Alignment Stages

- **AMOS Module**
  - AMOS Bench
  - AMOS Support Structure

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The heart of ASSIST is the DSM module. This element offers the mechanical support structure for the DSM and optics to re-image the light from a point source to normal incidence on the DSM and back to a point source. This allows both the use of a point-interferometer as well as inclusion of the DSM in the test setup for the AO systems. A fast test interferometer will be included for static and dynamic testing of the DSM. The Star Simulator and Turbulence Generator (SSTG) consists of two separate star simulators; one for the NGS sources and field calibration sources and a separate module for the defocused LGS. The latter will be interchanged between the testing of GALACSI and GRAAL, since in GRAAL mode, the LGS will be located at a modified conjugate altitude. The atmospheric turbulence will be simulated with a set of three phase plates at three different conjugate heights. The VLT focus simulator (VFS) will provide an exit beam with an output f-ratio and exit pupil location equals to that of the VLT.

jolissaint, 1/6/2009
## Requirements of ASSIST: Image Quality

<table>
<thead>
<tr>
<th>Mode</th>
<th>GALACSI NFM</th>
<th>GALACSI WFM</th>
<th>GRAAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific fov</td>
<td>7.5”x7.5” VIS &lt;16 mas</td>
<td>1’x1’ VIS &lt;0.1”</td>
<td>7.5’x7.5’ IR &lt;0.1”</td>
</tr>
<tr>
<td>NGS</td>
<td>7.5” IR &lt;42 mas</td>
<td>2.5’ VIS &lt;0.1”</td>
<td>15.2’ VIS &lt;0.1”</td>
</tr>
<tr>
<td>LGS</td>
<td>30” Na &lt;16 mas</td>
<td>2’ Na &lt;0.1”</td>
<td>8.2’ Na &lt;0.1”</td>
</tr>
</tbody>
</table>
Optics: AM1

ASSIST AM1 under full-tool polishing (left). The intermediate interferogram still shows deviations at the level of several fringes, which are now being removed (right).
Two copies of AM2 were ground into the correct aspherical shape (left), while one has now been completed to specification. The surface map shows a small step in the optical surface, but the overall specifications are still achieved.
The optical modules for ASSIST as made by Winlight. On the left is half of one of the large beam splitter cubes of ASSIST that combined the light from the laser guide star simulator and the natural guide star simulator. On the right is shown a collage of the various optical modules that ASSIST will be using.
The phase screens as manufactured by Silios (left) will be mounted in a mechanical mount with off-center rotation.
Star simulators

NGS simulator

LGS simulator
ASSIST: Mechanical Design

ASSIST currently weighs approximately 10,000 kg, which includes the DSM and the Nasmyth Adapter Rotator, and is 3.5x4.0x4.5 meters large.
The mechanical design of ASSIST follows the modular approach already described in the optical design, splitting the design of ASSIST up in three individual modules; the DSM module, the Star Simulator and Turbulence Generator (SSTG) module and the VLT Focus Simulator (VFS) module. Each of these modules has the property that they perfectly re-image from a focus to a focus, allowing for relatively easy individual testing of these modules. The overall mechanical layout of ASSIST is shown in Figure 6.

The structure is build up with the DSM tower as central element. This is a structure that will have to carry the DSM, with a weight of ~1750 kg and the AM1 mirror cell, with a weight of ~1300 kg. The distances between the different elements of the DSM tower also have the most strict requirements on the alignment (ASSIST will for example be out of specification with a change in distance between AM1 and AM2 of several 10s of millimeters) and should therefore be extremely stable. The SSTG platform contains all optics and mechanics for the SSTG. The system is built up of several modules, each containing a number of optical elements. Within each module the optics will be pre-aligned, after which the overall alignment of the SSTG is very much simplified; the tolerances on the internal alignment of the modules is set very strict to allow for a more relaxed alignment of the modules with respect to each other. The SSTG platform also contains the sources for both the LGS as well as the NGS. In case of the LGS, these sources will be extended sources to mimic the elongated shape of the LGS in the ~10 km high Na-layer. The NGS sources are located on a curved focal plane, which needs to be variable to allow for a good alignment of ASSIST.

The VFS is mounted on a support structure attached to the DSM tower. It contains sufficient alignment stages to allow for the final alignment of ASSIST with respect to the instrument under test, attached to the Nasmyth Rotator. The Nasmyth Adapter Rotator is directly attached to the DSM structure at multiple locations to allow for a stable interface between ASSIST and the instrument under test.
ASSIST: Mechanical Design
ASSIST: Alignment and Integration
ASSIST: Current status

- PDR: Sept 2007
- FDR: June 2009
- MRR: Dec 2009
- ARR: Jan 2011
- Assembly and Integration: May 2011 at ESO
- DSM: ADS Microgate
- AM1 AM2: AMOS, Belgium
- AM2: Astron, The Netherlands
- Optical Modules: Winlight Optics, Marsielle
- Mechanics: Boessenkool, Almelo & Leiden Workshop
The distance from the centre of a typical elliptical that can be probed with ELT.