News of the MUSE

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We report on progress of the Multi Unit Spectroscopic Explorer (MUSE), a second generation VLT panoramic integral field spectrograph. MUSE is now in its final phase of integration, testing and validation in Europe. The instrument is described and some results of its measured performance are shown.

The Multi Unit Spectroscopic Explorer (MUSE) is a second generation Very Large Telescope (VLT) panoramic integral field spectrograph. MUSE has a field of 1 × 1 arcminutes, sampled at 0.2 × 0.2 arcseconds and is assisted by the VLT ground layer adaptive optics facility using four laser guide stars (Arsenault et al., 2010). The simultaneous spectral range is 0.465–0.93 μm, at a spectral resolution of ~ 3000. MUSE couples the discovery potential of a large imaging device to the measuring capabilities of a high-quality spectrograph, while taking advantage of the increased spatial resolution provided by adaptive optics. MUSE also has a high spatial resolution mode with a 7.5 × 7.5 arcsecond field of view sampled at 25 milliarcseconds. In this mode MUSE should be able to obtain diffraction-limited datacubes in the 0.6–0.93 μm wavelength range.

MUSE has been presented in Bacon et al. (2006). At that time the project was in an early stage (preliminary design phase). Meanwhile the concept has transformed into an impressive piece of hardware. MUSE is now entering its very final phase of integration, testing and validation in Europe.

The MUSE hardware is composed of 24 identical modules, each consisting of an advanced slicer, a spectrograph and a 4k × 4k pixel detector. A series of fore-optics and splitting and relay optics derotates and partitions the square field of view into 24 sub-fields. These optics systems will be placed on the Nasmyth platform between the VLT Nasmyth focal plane and the 24 integral field unit (IFU) modules.

Instrument innovations

Among the numerous technical innovations utilised in the instrument it is worth mentioning a few important achievements.

The slicer, a key element of the project, is a compact stack of spherical off-axis two-mirror systems. Each slicer incorporates an array of 48 thin slices, which are assembled with a very high precision, and kept in place by optical contacting. This array faces another array of 48 small off-axis spherical pupil mirrors. The system rearranges the input image geometrically into 48 small pseudo-slits with only two optical reflections. This guarantees the highest possible throughput. The production of the 24 slicers, i.e., 2304 high precision optical elements, has been contracted to Winlight Optics. In January 2012, they delivered 23 slicers and the remaining one is expected very soon. It took a significant time to fine tune the industrial production and alignment pro-

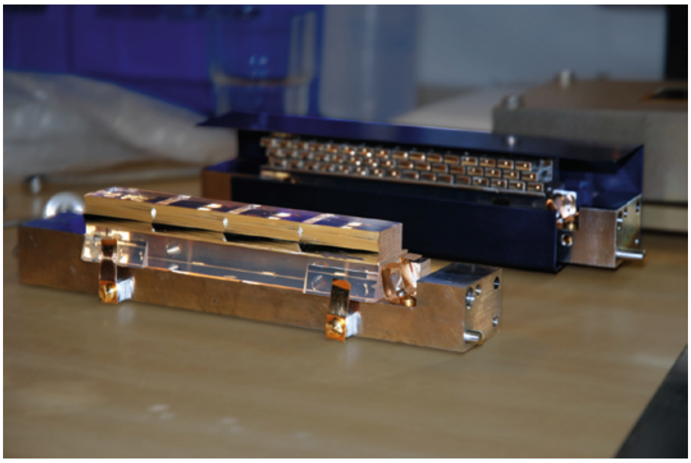

Figure 1. One of MUSE's slicer image dissectors and the focusing mirror arrays are shown before assembly in the laboratory.

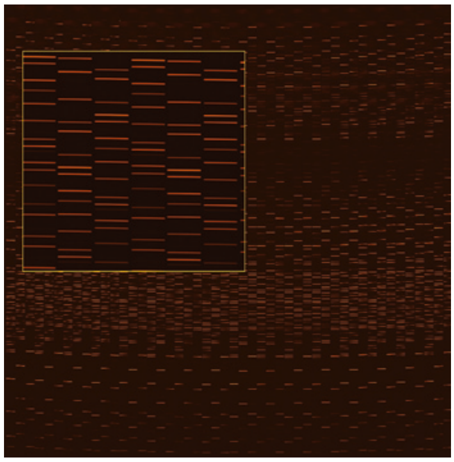

Figure 2. IFU technical first light image. This image shows the first exposure of a complete IFU obtained in the laboratory. This picture was obtained by exposing the IFU to a set of neon, xenon and mercury–cadmium arc lamps for a few seconds. Part of the image is zoomed to display the arc lamp emission lines produced by six slices in more detail.

cesses, but today all the slicers we have in hand achieve very high performance. Figure 1 shows one of the assembled slicers.

Each slicer is located at the entrance of a spectrograph. The 24 spectrographs have a compact design and incorporate a wide spectral range volume phase holographic (VPH) grating specifically designed for MUSE by Kaiser Optical Systems. Winlight is also in charge of spectrograph production, and has delivered 19 units so far. After alignment, the slicer is attached to the front part of the spectrograph, while the detector vessel connects to the rear side. This assembly constitutes one integral field unit. The system is then aligned and qualified. The performance of each IFU is carefully checked and monitored. The IFU point spread function is a major contributor to the overall image quality budget and determines the final spectral performance. We are pleased to report that the IFUs achieve a very high and homogeneous image quality, even better than the original specifications, which were already considered as tight. Figure 2 shows the first image of an exposure of an arc lamp.

Each detector vessel incorporates one 4k × 4k 15 μm deep depletion CCD device with improved quantum efficiency in the red wavelength range. The company e2v delivered 26 top quality detectors to ESO. These detectors implement an innovative graded index anti-reflection coating, which is optimised according to the wavelength of light hitting each pixel of the detector. This gives a significant boost to the quantum efficiency and reduces the fringing. All the CCDs have been mounted in their detector heads, and have been characterised by the optical detector team at ESO, and found to be within specification. As proper align-

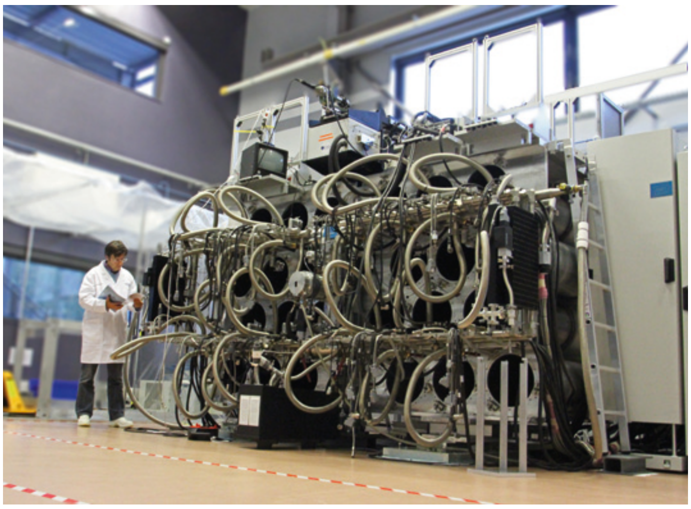

Figure 3. Rear view of MUSE in the CRAL integration hall, showing the large cryogenic system in charge of cooling and vacuum control for the 24 cryostats. The large IFU holes in the main structure are visible between the cooling cables.

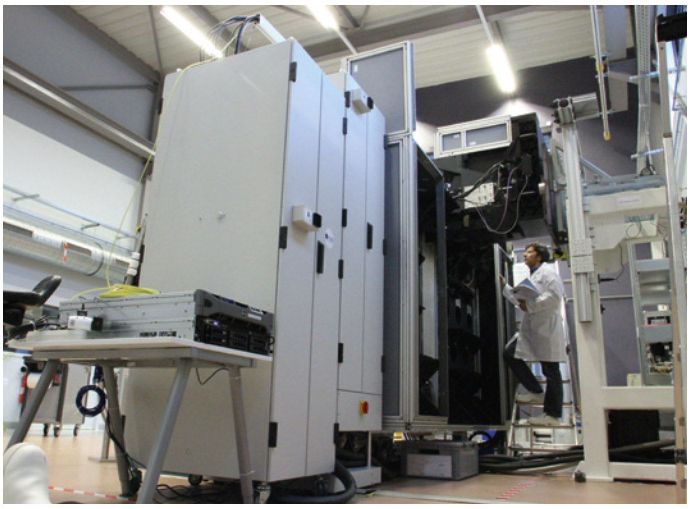

Figure 4. Front view of MUSE in the CRAL integration hall. The two electronics cabinets (one for the cooling system, the other for the fore-optics and calibration unit mechanism and lamps) can be seen in the foreground. The front part of the fore-optics is visible at the top of the main structure. It faces an optical system which simulates the VLT light beam.

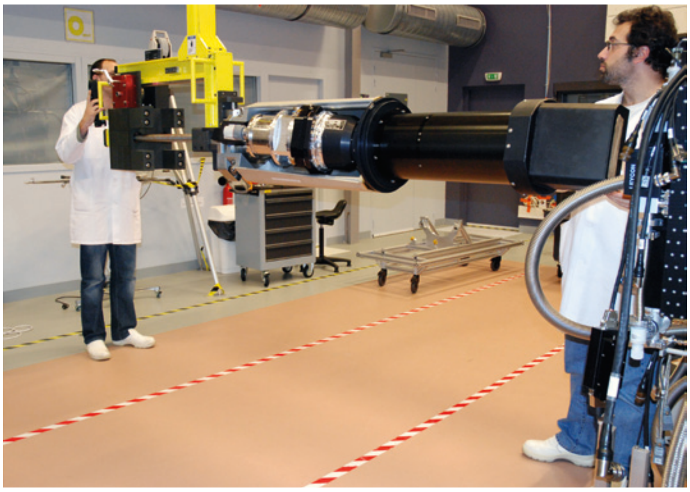

Figure 5. First IFU insertion. One complete IFU is visible before its insertion into the main structure. A dedicated tool (in yellow) has been built to ease the insertion while minimising the risk of damaging the delicate image slicer, located in the front of the IFU, or the cables of the cooling system.

Figure 6. The fore-optics system attached to the integration hall crane can be seen before its descent onto the main structure.

ment of the detector with respect to the spectrograph is critical, the 24 completed detector heads have been systematically checked at AIP in Potsdam using a single reference spectrograph.

To improve further the total efficiency of the instrument, we have replaced the protected enhanced silver coating originally envisioned for the seven mirrors of the optical train by a dedicated 80-layer dielectric coating from Balzers Optics. The solution was extensively tested for durability under severe constraints: humidity, temperature change and scratch. The stress induced by the optical coatings on the substrates was also checked and found to be tolerable.

Integration at CRAL

Early in 2011, ESO finalised the construction of the impressive vacuum and cryogenic system, based on liquid N_2 continuous flow cryostats, and its control electronics, and delivered it to CRAL in Lyon. It was followed a few months later by the equally impressive MUSE main structure from IAG, the fore-optics subsystem from IRAP, and the calibration unit from AIP. Figure 3 shows a rear view of the main structure and Figure 4 a view from the front. The pieces were put together and a first IFU inserted (see Figures 5 and 6). A first set of mirrors and lenses of the splitting and relay optics has been aligned such that we obtained first light in late December, involving a full optical path, from the calibration unit to the detector plane. Fine alignment is in progress, but we can already confirm the excellent image quality of the system; a wonderful Christmas gift.

In parallel to the visible hardware assembly, a lot of effort has gone into the control and data reduction software. Full-scale tests with simulated astrophysical scenes have started and demonstrate that the system is able to handle the huge data volume provided by the instrument.

We are now proceeding to align and assess the performance of the 24 channels, in parallel with the alignment of the remaining IFUs. The global tests and performance verification will be concluded by the preliminary acceptance review in Europe (PAE), which is expected in October this year. The instrument will then be sent to Paranal for the re-integration and commissioning phase. This period is expected to take a significant fraction of 2013.

Prospects

With its 400 megapixels per frame and 90 000 spectra in one exposure, MUSE is already the largest integral field spectrograph ever built. The performance measured in the laboratory demonstrates that it should also meet its very ambitious specifications on the telescope. In some critical areas such as image quality and throughput it is even better than the original specifications. Once installed at the Nasmyth focus of the VLT's Unit Telescope 4, MUSE will immediately provide the ESO community with a unique and powerful tool to address key scientific questions in a large number of astrophysical fields. A year later MUSE will be coupled to the Adaptive Optics Facility (Arsenault et al., 2010) using the GALACSI adaptive optics module. The expected spectacular gain achieved in spatial resolution without any loss in throughput and with almost full sky coverage will boost the MUSE performance by another substantial factor.

References

Arsenault, R. et al. 2010, The Messenger, 142, 12
Bacon, R. et al. 2006, The Messenger, 124, 5

Links

MUSE public website: http://muse.univ-lyon1.fr