Progress Report on X-shooter, the first second-generation VLT instrument

X-shooter is the first of the approved second-generation VLT instruments to have completed the Preliminary Design Phase. Here we give an update of developments in the project since its official launch in December 2003.

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X-shooter is a single target spectrograph for the Cassegrain focus of one of the VLT UTs, covering in a single exposure the wide spectral range from the UV- to the *K*-band. It is designed to maximize the sensitivity by directing the light to three wavelength-optimized spectrograph arms. The possibility to observe faint sources with an unknown flux distribution in a single shot inspired the name of the instrument. A first report on X-shooter was contained in the article "New VLT Instruments Underway" by A. Moorwood and S. D'Odorico at the time of project approval (2004, The Messenger 115, page 8).

After the telescope focal plane the light beam is split in three spectral ranges (UV-Blue, Visual-Red and NIR) by two dichroics and focused by auxiliary optics on three separate slits. Each spectrograph arm has optimized optics, coatings, dispersive elements and detectors and operates at intermediate resolution (R = 4000–14000, depending on the arm and the slit width) sufficient to address quantitatively a vast number of astrophysical applications while working in the background-limited S/N regime in the regions of the spectrum that are free from strong atmospheric emission and absorption lines.

A small Integral Field Unit (IFU) covering an area of 4 × 1.8 arcsec on the sky can be inserted in the focal plane and reformats this field as a 0.6 × 12 arcsec slit. This option can be used in time of poor seeing, for spectroscopy of slightly extended objects or for quick pointing of targets with coordinates known to 1 arcsec rms accuracy.

The small number of moving functions and instrument modes and the fixed spectral formats make the instrument simple and easy to operate and permit a fast response. With its capability to observe single objects over a wide spectral range at the sky limit, the X-shooter will be a cornerstone facility for the VLT.

The main scientific objectives of X-shooter have been elaborated during Phase A and are summarized in Table 1. The main instrument parameters are listed in Table 2.

During the Preliminary Design Phase, much time and effort has gone into optimizing the instrument mass and minimizing flexure as a function of telescope position. Two types of flexures can affect the quality of X-shooter observations: the relative motions of the three entrance slits (which has to be minimized to avoid losses in one arm with respect to the others) and those between the slits and the detector planes (which could degrade the accuracy of the wavelength and flat-field calibrations) These critical issues were already identified during the Phase A study and are due to the instrument location at Cassegrain, the weight and torque limits that apply for this focus and by the fact that from a mechanical point of view, X-shooter is an instrument cluster, rather than a single instrument. Access for adjustment and maintenance has also been a driver to this design optimization. The layout of the instrument that resulted from these optimization studies is found in Figure 1. For the flexures, while the FEA calculations are being consolidated and compared with the specifications, we do not exclude the possibility to introduce at FDR active mirror controls to compensate the slit motions.

On the optical side it was decided to change the original UVES-type white-pupil layout to a new type of white pupil layout

Table 1: Science drivers for X-shooter

- Spectral properties of forming stars
- Properties of cool white dwarfs
- The nature of neutron stars in close binary systems
- Physical processes in the atmospheres of brown dwarfs
- Properties of core-collapse supernovae
- Type Ia supernovae to $z = 1.7$
- Gamma-ray bursts as high-energy laboratories and cosmological probes of the intergalactic medium
- The role of faint emission line galaxies in the redshift interval $z = 1.6–2.6$
- Properties of high mass star formation and massive galaxies at high z
- Metal enrichment in the early universe through the study of absorption systems
- Tomography of the Intergalactic Medium through the observations of faint background QSOs

Table 2: X-shooter characteristics

Spectral Format	Prism cross-dispersed echelle
Wavelength range	300–2500 nm, split in 3 arms using dichroics UVB: 300–550 nm VIS: 550–1000 nm NIR: 1000–2500 nm
Spectral resolution	5000 (UVB, NIR) and 7000 (VIS) for a 1 arcsec slit
Slits	slit 12″ × 1″ (standard), 12″ × 0.6″ (high R), 12″ × 5″ (flux cal.) IFU 4″ × 1.8″ input area, 12″ × 0.6″ exit slit (3 slices)
Detectors	UVB: 2k × 4k E2V VIS: 2k × 4k MIT/LL IR: 2k × 2k Rockwell Hawaii-2RG MBE (used area 1 k × 2 k)
Auxiliary functions	Calibration Unit; A & G unit with 1′ × 1′ field and filter set; ADC for the UVB and VIS arms

dubbed 4C (for Collimator Correction of Camera Chromatism). An important advantage of 4C is the small and simple camera and the fact that prisms are used in double pass which reduces the number of prisms, hence cost and weight. The NIR optical layout and spectral format are shown in Figure 2.

The PDR was successfully passed in December 2004 (March 2005 for the Data Flow aspects of the project). Recommendations of the review board were to also cover the astrophysically very important *K*-band with the NIR instrument if this could be done without losses in the other bands and to suppress the planned closed-cycle cooler, the vibrations of which might interfere with interferometry. These modifications are now being implemented. They were facilitated by rapid technical developments in low-background IR detectors at Rockwell (as confirmed in recent laboratory tests at ESO and demonstrated by the good performance of the 2 k × 2 k Hawaii-2RG array in SINFONI). In Figure 3 we show the minimum DQE of the detectors that ESO is confident to install on the instrument. The PDR of the Data Flow addressed the expected impact of the instrument operation on the observatory, the specifications for calibration and the exposure time calculator, the requirements on the Data Reduction Software and the specification of the routines from which the pipeline data reduction will be built up.

The design and specification documents for long-lead items like optics, gratings and NIR detector are currently being prepared and will be reviewed in Q2 of this year to permit early ordering. For the IFU module a prototype has been built in Paris and is undergoing the first tests (Figure 4, next page). The instrument FDR will take place around the end of this year; the exact date depends on the outcome of the ongoing adjustments to the PDR design. First light on the telescope is expected for late 2007 with instrument release in October 2008.

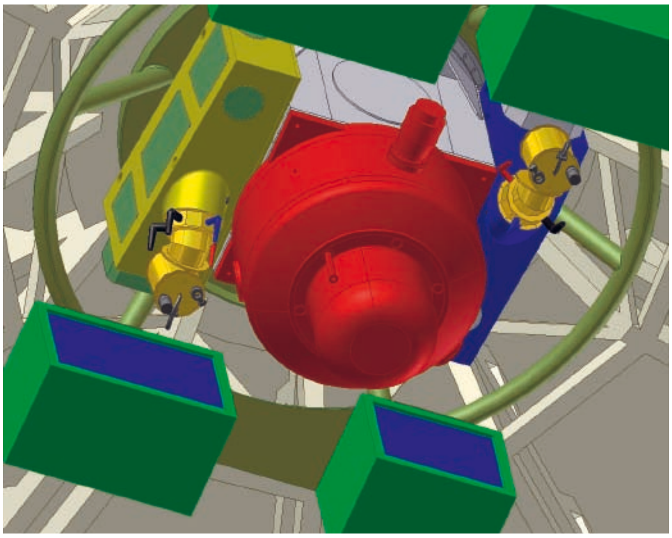
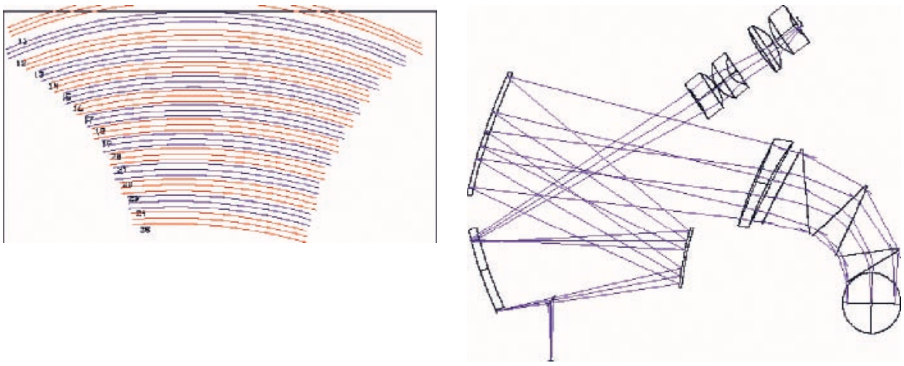


Figure 1 (above): View of X-shooter attached to the Cassegrain focus of the telescope. Compared to the Phase A design, the electronics are no longer supported by the main structure (backbone) but by a co-rotating ring. This reduces flexure and improves access. The NIR spectrograph is mounted below the backbone (3D view from Copenhagen Observatory).

Figure 2 (below): The white-pupil optical layout of the NIR spectrograph (panel on the right). The chromatism of the corrector plate (just in front of the first prism) is used to help correct the camera which consists of only four lenses. The collimated beam on the grating is 85 mm. Since the pupil mirror re-images the grating on the camera mouth at 2× demagnification, the camera is compact and inexpensive.
The left panel shows the spectral format which covers the range 1.03–2.48 μm in 15 orders over a 1k × 2k section of a Rockwell 2k × 2k array. The order separation is nearly constant due to the use of ZnSe and Fused Silica prisms, which leads to efficient use of IR detector area (optical design by ESO and the Dutch and Italian partners of the Consortium).



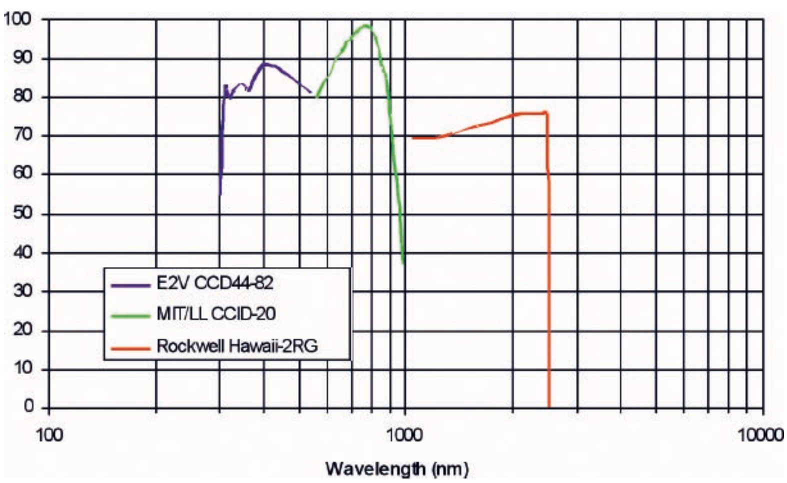


Figure 3 (left): DQE curves of the detector chips that have been selected for X-shooter. The CCDs are in-house and were measured by the ESO Optical detector team. The IR detector is on the shelf at Rockwell and is reserved for X-shooter. Dichroic crossover points are at 557 and 1019 nm. The wavelength range of X-shooter spans more than three octaves.

X-shooter is being built with – in exchange for guaranteed time – a large manpower and financial contribution from institutes in four ESO member nations. In the course of 2004 all required national funding has been secured. The total effort amounts to 67 person-years and 5.3 M€, of which ESO contributes 22 % and 28 %, respectively. The large external financial contribution is unusual in VLT instrument projects but in the case of X-shooter it allows rapid advancement of the project, decoupling it from cash flow limitations in the VLT instrumentation budget. Table 3 lists the co-PIs and collaborating institutes and their main technical contributions. The two agreements with Italy and Denmark have been signed in 2004, the one with France in April 2005 (Figure 5) and the one with the Netherlands is being signed as this issue of the Messenger goes to print.

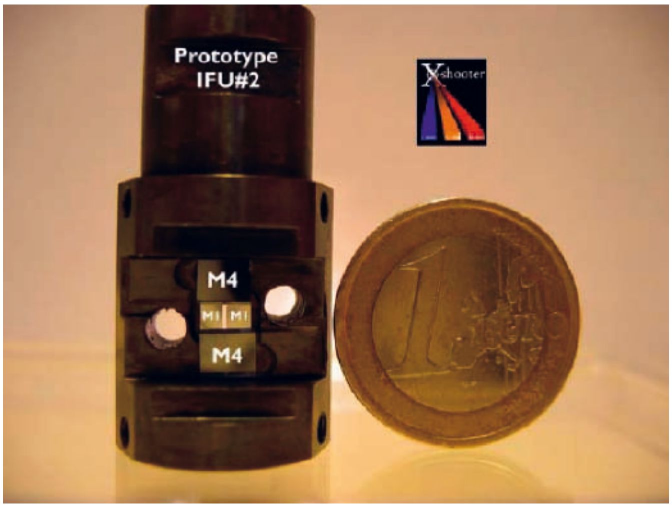


Figure 4: Part of the prototype of the IFU assembled for performance test at the laboratory of the GEPI Department of the Observatory of Paris-Meudon. View is on the input side. The IFU will reformat a field of 1.8 x 4 $arcsec^2$ in the sky into a slit of 0.6 x 12 $arcsec^2$. The central slice of 0.6 x 4 $arcsec^2$ can be seen between the two M1 mirrors.

Table 3: PIs, collaborating institutes and their contributions

PI and collaborating institutes	Contribution
Per Kjærgaard-Rasmussen Copenhagen University Observatory	Backbone unit, UVB spectrograph, Mechanical design and FEA, Control electronics
Sandro D'Odorico ESO	Project Management and Systems Engineering, Detector systems, optical design, various aspects of the Data Flow at the VLT, final system integration, commissioning, logistics
François Hammer Paris-Meudon Observatory, Paris VII University	Integral Field Unit, Data Reduction Software
Roberto Pallavicini Observatories of Brera, Catania, Trieste and Palermo	VIS spectrograph, Instrument Control Software, optomechanical design, integration and test of UVB and VIS spectrographs
Lex Kaper Astron, Universities of Amsterdam and Nijmegen	Opto-mechanics of cryogenic NIR spectrograph, contribution to Data Reduction Software

Figure 5: Daniel Egret, President of the Observatoire de Paris, welcomes Catherine Cesarsky, Director General of ESO, and the French participants to the project on the day of the signature of the X-shooter Agreement between ESO and the Observatoire (1 April 2005).