UVES at Kueyen: Bright Prospects for High-Resolution Spectroscopy at the VLT

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After the successful completion of the commissioning period, the UV-Visual Echelle Spectrograph starts regular operation at the Paranal Observatory.

Introduction

The ESO scientific community has a rich tradition of research based on the detailed analysis of high-resolution spectra of stars. One of the very first spectrographs to enter into operation at ESO was in 1968 the coudé high-resolution spectrograph at the 1.52-m at La Silla, followed in 1973 by the Echelec at the same telescope.

The first ESO-built echelle spectrograph for the 3.6-m, CASPEC, was installed in 1983 and opened the possibility to study faint stellar and extragalactic sources, thanks to its new (at that time almost exotic) CCD detector (a high efficiency 320 × 512 RCA CCD, with a read-out-noise of 40 e⁻/pixel and a dark current of 15 e⁻/hr/pixel). For the first time, the ESO community had access to an instrument that was fully competitive with, and in some areas superior to, other high-resolution spectrographs at large telescopes worldwide. CASPEC was followed by the CES spectrograph coupled to the 1.5-m CAT giving resolving powers larger than 100,000 on stars down to magnitudes ~ 10 and in 1991 by the echelle mode of the EMMI spectrograph at the NTT, which again offered optimal performance in R = 25,000 spectroscopy of faint sources in the visual-red spectral region.

In 1993, the HIRES echelle spectrograph came into operation at the first 10-m Keck telescope. The excellent quality of the instrument and the collecting power of the largest telescope ever built successfully combined to form a unique tool for all programmes, which require spectra of faint targets at resolution up to 50,000 in the 400–800 nm range. ESO astronomers working on research topics, which rely on high-resolution spectra, for both stellar and extragalactic targets, often had to face a powerful, almost unbeatable competition or to concentrate on objects at declinations lower than –40 degrees. After six years of justified frustration, the ESO community has now access to an instrument, UVES, which is more efficient, provides larger spectral coverage in a single exposure, and can reach higher resolving power with proper sampling than its main competitor in its present configuration.

Not surprisingly, in the first semester of Kueyen observations (Period 65, starting April 1, 2000), about 70% of the time has been assigned to UVES observations. The Observing Programmes Committee has selected programmes for 78 nights in UVES visitor mode and for 312 hours of service observations. Scanning through the titles of these approved programmes, we find most of the research topics identified as scientific drivers of the instrument when it was first proposed. Going from the very close to the distant universe, UVES observations will aim at highly accurate radial velocity measurements of nearby stars to search for associated planets, at the determination of the abundance of various critical elements in the atmospheres of stars in the Galaxy and in nearby systems and at the study of absorption systems down to the atmospheric cut-off in QSO's spectra.

Figure 1: This areal view of the Nasmyth platform of Kueyen at the end of the integration shows UVES with the top of its enclosure partially lifted to have access to the table where the various components are mounted. The bar connecting the enclosure to the telescope fork is for safety in case of earthquake.

The Instrument Layout

There are a few basic choices taken early in the project which have been crucial in determining its present good performance: the configuration fixed with respect to gravity (advantages: less weight and space restrictions, more stability, shortcomings: need of derotator and more relay optics), the splitting of the optical path in a UV-blue and in a visual-red arm (giving the possibility to optimise the efficiency over the entire spectral range from 300 to 1000 nm) and the early selection of detectors of a format (2k × 4k, 15 μm pixels) for which we had to find a supplier who would deliver to specifications. The optical design of both arms is of the white pupil type. To maximise the resolution while keeping the beam size reasonable (200 mm) we went for two 214 × 840 mm mosaics (each made by two replicas on a single blank) R4 echelle gratings, the first ones of this type and size ever produced. The design of UVES is fully ESO made, the various components were produced in Europe and the USA: the optics in France, the mechanics in Germany and Switzerland, the gratings in the USA and Russia, the detectors in the UK and USA and most of the high-level software in Italy at the Observatory of Trieste.

Two main parts compose UVES (see Fig. 1). The preslit area is attached to the Nasmyth rotator and includes the *calibration unit* with the arc lamp and different FF lamps for each spectral range, an insertable *iodine cell*, a slide mounting three *image slicers* for observations at the highest resolution in mediocre seeing conditions and the *derotator*. Along the optical path, now on the steel table bolted to the Nasmyth platform, the beam encounters the *atmospheric dispersion corrector, a depolarise slide, a variable pupil stop and the arm selector unit*, which can feed the two arms individually or in parallel with *dichroics*. The blue and red *slit units* are adjustable in width and height, they reflect the light over a field of 30 arcsec diameter to two CCDs which are used for target acquisition and centring, for monitoring the telescope guiding and for recording the slit position on the sky. After the slits, each of the two parallel arms (which intersect each other to minimise the overall volume) includes an *order sorter filter wheel*, *the collimator mirrors, the echelle grating, the exposimeter and the cross-disperser unit* with two gratings mounted back to back. The *cameras* are dioptric with an external focus to facilitate detector exchange; the largest lenses are CaF2 (220 mm diameter) and SFPL51 (246 mm) in the blue and red respectively. The blue-arm CCD is an EEV-44 device with enhanced UV efficiency (55% at 340nm). The red detector is a mosaic of one EEV-44 device and one MIT-LL CCID-20 device, to optimise the spectral response with wavelength. The CCDs are operated by the ESO-built FIERA controller. In the configurations they are offered in UVES, both detectors are read out in ~ 40 s with a rather good r.o.n. of 2 and 4 e^- r.m.s. The operating temperature of the CCDs (~ 150° K) is maintained by liquid nitrogen fed from a tank which secures an autonomy of at least 10 days. The table is protected from dust and light by a motorised enclosure that can be lifted to give access to the functions. It provides a passive thermal insulation which, combined with the air conditioning of the telescope enclosure during the day, smoothes out the temperature variations inside the instrument.

Figure 2: During the frantic days of the instrument integration at the telescope, J.L. Lizon takes advantage of the robust design of the UVES functions for a short rest. Most of the subsystems are already mounted on the table fixed to the Nasmyth platform: from the left the preslit units, the shiny back of the blue echelle mount, the blue CD unit, camera and CCD.

A more detailed description of the spectrograph and its main components can be found in the UVES User Manual and in Dekker et al. (Proceedings of the SPIE Conference 4008, Munich, 2000).

Who is Who in the UVES Project?

The table includes the names of the engineers, technicians and astronomers who have contributed to the design, building and testing of the various subsystems and of the instrument in the last seven years. This serves as recognition of a job well done and also as a reminder of the different expertises that are needed to complete and put successfully into operation a complex instrument at the VLT. Starting from the optical designer to the astronomers who verify the quality of the first astronomical data, from the skilled technicians who integrate and test the opto-mechanical functions to the software specialists who wrote more than 140,000 lines of code for instrument control, all had to complete their task properly and in schedule for the instrument to be successful. A total of approximately 40 person-years and 6.7 MDM went into project.

TABLE 1. THE UVES TEAM

Project Manager, Optical Engineering:	*H. Dekker*
Instrument Scientist:	*S. D'Odorico*
Optical Design:	*B. Delabre*
Mechanical Engineering and Design:	*H. Kotzlowski, G. Hess*
Control Electronics:	*S. Moureau*
Control Software:	*A. Longinotti, P. Santin and P. Dimarcantonio (Obs.Trieste), R. Schmutzer*
CCD Detector Integration and Testing:	*R. Dorn, C. Cumani*
Opto-mechanical Integration and Testing, Cryogenics:	*J.L. Lizon à l'Allemand, C. Dupuy, A. Silber*
Data Flow System (Pipeline, Instrument Model and ETC, P2PP):	*P. Ballester, O. Boitquin, M. Chavan, A. Modigliani, S. Wolf*
Testing in Europe, Commissioning, Calibration and Operation at Paranal:	*A. Kaufer*
Astronomical Support, Documentation, Data Reduction, Testing of Pipeline:	*S. Cristiani, V. Hill, L. Kaper, T. Kim, F. Primas*

(All from ESO, except where indicated differently)

UVES through Commissioning

Hardware and software were first put together, tested and optimised in the ESO Integration Laboratory in Garching. The results in the laboratory confirmed the quality of the optics, the capability to reach the specified resolving power, and the robust, reliable behaviour of the electro-mechanics and of the software. The tests were completed in May 1999, the instrument was then fully dismounted, its hundreds of components properly packed and sent part by plane, part by ship to Chile. At

Figure 3: After the successful first light, part of the UVES team proudly poses close to the instrument with its partially lifted enclosure. From the left, back: A. Kaufer, C. Dupuy; front: A. Longinotti, P. Santin, P. Dimarcantonio, H. Dekker, S. Moureau and R. Schmutzer. The almost total compliance with the Observatory safety regulations, even at a time of undisputed euphoria, is worth praise.

the Observatory, first the table was installed on the Nasmyth platform of UT2, the Kueyen Telescope, and then the complex layout of optics, mechanics, cables, detectors was reassembled and the optical path re-aligned (Fig. 2). We went through this usually critical phase (it is the time one discovers whether proper care has been taken of the interfaces with the telescope) with a minimum of bad surprises: a few holes were not in the right places, the table plane a few millimetres below the expected height. The optics, and especially the large lenses of the cameras had survived the loading from the plane and the bumpy road from Antofagasta to Paranal but the blue camera did show a degraded optical quality and had to be dismounted and re-aligned. In the last week of September, we were finally ready and eager to verify whether the operation of UVES at the telescope and its overall efficiency on the sky were in line with the model prediction. A crucial point to check was the acquisition and guiding of the targets on the slit plane and the parallel operation of the two arms in the dichroic modes.

The first stellar photons entered the spectrograph on September 26. Jason Spyromilio and Anders Wallander had just concluded the commissioning on the Kueyen telescope with the Test Camera reporting record performance in image quality and tracking performance. We had already gone through extensive testing and optimisation with the calibration lamps and knew that the instrument's optical quality was basically all right. The first target was a flux standard star. From the very beginning we were ready to carry out target acquisition, instrument setting, observations and archiving of the data starting from Observation Blocks prepared in advance with the instrument templates. We launched the first OB and the star landed within one arcsecond from both slits and was centred without problems (except the mandatory wrong sign in one of the formula to convert pixels to coordinates) using the slit viewers. On the same night, a quick analysis of the spectra produced an overall efficiency that is very close to the predicted values at all wavelengths but in the far-red region. The following night, on September 27 (the official first light) was blessed by a seeing between 0.6 and 0.4 for 90% of the time and we could confirm the capability of UVES on the first scientific targets (see the ESO 15/99 press release on the ESO Web pages). At that point, we knew that with UVES+Kueyen, we had on line the most powerful combination for high-resolution spectroscopy available to the astronomical community worldwide. It was, and still is, a nice feeling which helped us to go through the subsequent less exciting but necessary three weeks of testing and calibration of all the instrument modes, of the acquisition procedures and of the software interfaces.

The smoothness of the commissioning of UVES is best testified by the very low number of hours lost due to technical problems of the telescope or instrument: around 7 in total over three weeks of continuous operation, of which three were due to the sudden death of the power supplier of the instrument WS, three to a failure of the telescope M2 unit, due to a gust of wind well above the safe operation conditions and one to a rebooting of the instrument control software.

A substantial chunk of data of scientific value taken for Commissioning has been released with their calibration for public use. They correspond to more than 94 hours of integration on the sky.

A second, shorter commissioning period in December was mainly dedicated to the optimisation of the blue arm optical alignment, to the test of the iodine cell and the final editing of the instrument observing templates.

The performance of the instrument at the time of the handing-over to the Observatory in December 1999 is summarised in Table 2. An additional important parameter is the stability of the wavelength calibration. When allowance is made for the variation of the refractive index of air with temperature and pressure (both recorded in the file headers), the velocity stability of the

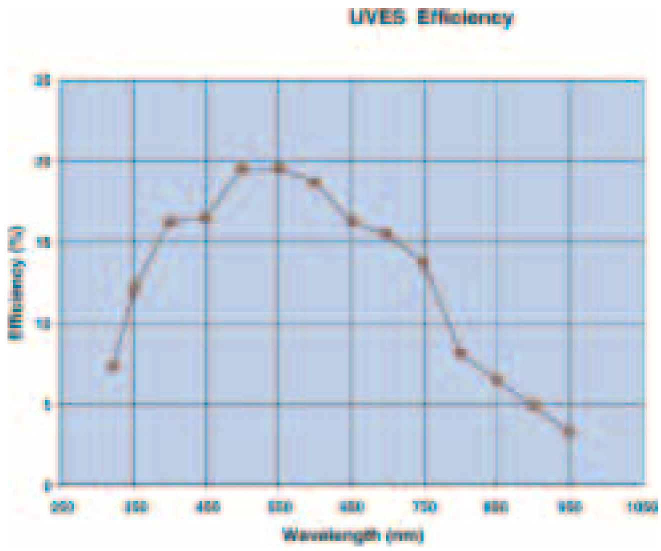

Figure 4: The overall efficiency of UVES derived from observations of the standard stars EG21 and Fei 110 taken with a wide open slit. The values refer to the top of the blaze function in each order and have been obtained from observations with two dichroic standard settings. They are corrected for losses in the atmosphere and in the three-mirror reflections of the telescope. The decrease of efficiency toward the UV and the far-infrared are mostly due to the lower efficiency of the CCDs and of the cross-disperser gratings at these wavelengths. Both components could be easily substituted with new ones of higher performance, when they become available.

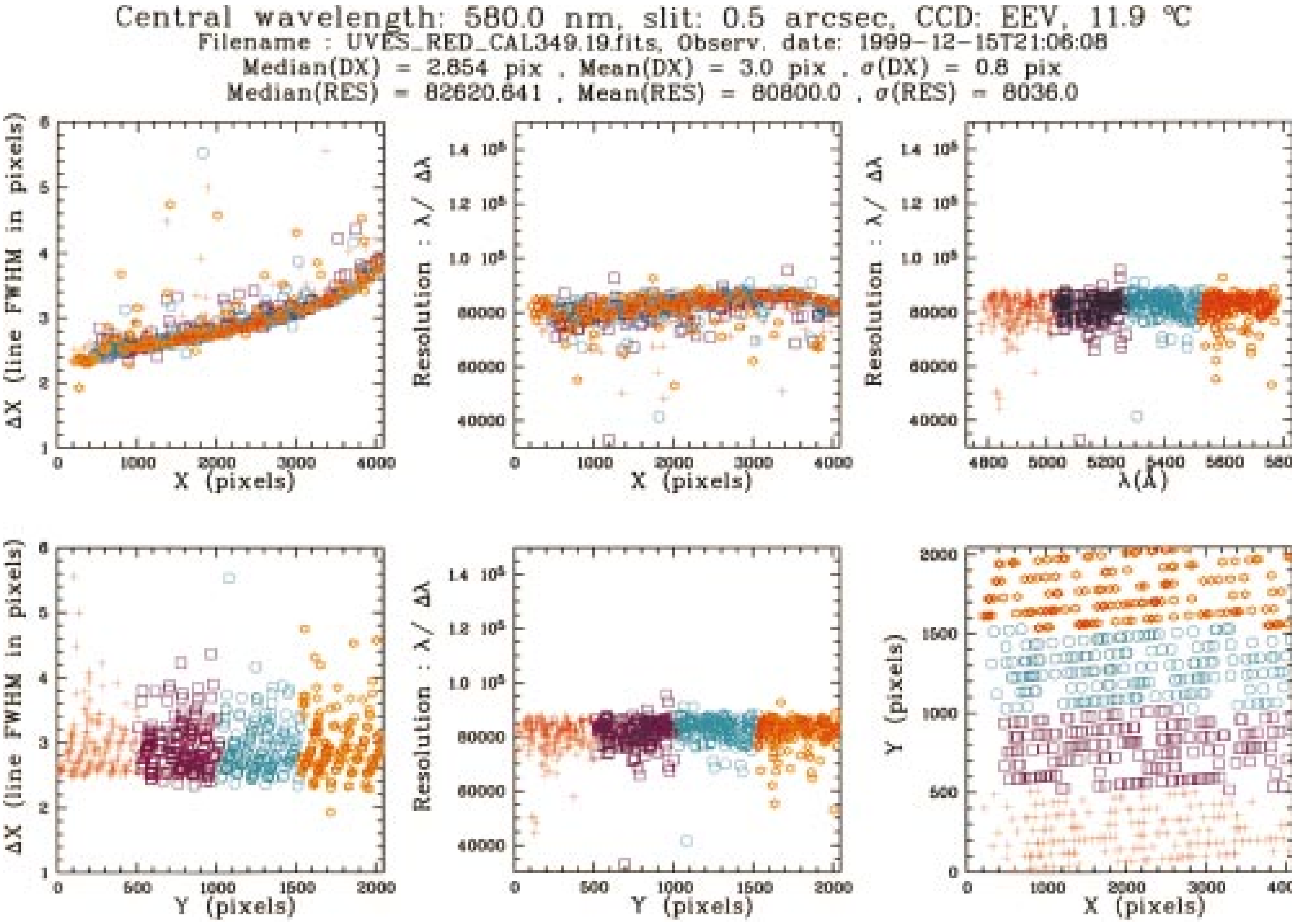

Figure 5: This plot, a by-product of the automatic data-reduction pipeline running for the instrument standard wavelength settings, maps the instrument resolution from measurements of the FWHM widths of the lines of the ThA lamp distributed over the whole CCD (see subplot bottom-right). Resolution and FWHM in pixels for each line are given as a function of position on the chip and wavelength. This particular diagram refers to a spectrum obtained with a 0.5-arcsec-wide slit and to the region covered by the EEV CCD-44 chip in the red arm.

instrument over days was found to be of the order of 50 m/s. The use of the iodine cell, not yet tested in full, should further lower this limit to a few meters/sec but it requires an effort by a specialised team on the data-reduction software.

While the overall status of the instrument at the end of Commissioning is very satisfactory, there are a few pending problems on which we need to work. The tracking of targets observed with the image slicers was found to require an unplanned modification of the TCS. The Cross-Dispersers #1 and #4

TABLE 2. UVES OBSERVING CAPABILITIES AND MEASURED PERFORMANCE

	Blue Arm	**Red Arm**
Wavelength range	300 –500 nm	420 –1100 nm
Echelle	41.59 g/mm, R4 2 mosaicked replicas on a Zerodur block	31.6 g/mm, R4 2 mosaicked replicas on a Zerodur block
Cross-dispersers	CD1: 1000 g/mm, λ_b 430 nm CD2: 660 g/mm, λ_b 460 nm	CD3: 600 g/mm, λ_b 560 nm CD4: 312 g/mm, λ_b 770 nm
CCD format and pixel scale ⊥ disp (1 pixel = 15 µm)	2048 × 4096, windowed to 2k × 3k (.25“/pix)	4096 × 4096, 2 x 1 mosaic (.18”/pix)
Resolution-slit product/wavelength bin	41400 0.0019 nm at 450 nm	38700 0.0025 nm at 600 nm
Max. resolution	80,000 (0.4” slit or IS)	115,000 (0.3” slit or IS)
Throughput (TEL+UVES, no slit, no atmosphere)	10 % at 400 nm	12% at 600 nm
Limiting magnitude (90m. exp., S/N =10, 0.7” slit & seeing)	18 (R = 58,000) at 360 nm	19.2 (R = 62,000) at 600 nm
λλ/frame,CD1, CD3 CD2, CD4	85 nm in 33 orders 126 nm in 31 orders	200 nm in 37 orders 403nm in 33 orders
Order separation (minimum)	10“ ↔ 40 pixels	12“ ↔ 70 pixels

are not the ones ordered for the instrument but prototypes of inferior quality. This results in a lower efficiency especially in the far red and in stronger optical ghosts in the UV and far red (in the most unfavourable configurations up to a few per cent of the primary spectrum). The final gratings should be installed by the end of this year.

In February 2000, UVES was used in service mode for nine nights of Science Verification on a variety of scientific programmes (see for details http://www.eso.org/science/ut2sv).

Everything went smoothly and the weather co-operated: a total of more than 70 hours of integration mostly in excellent seeing conditions were successfully completed. The data will be released to the community in late spring.

Acknowledgements

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In the framework of a long-standing collaboration with ESO, the Observatory of Trieste provided a substantial, highly professional contribution to the project with the work of P. Santin and P. Dimarcantonio on the instrument control, observing and maintenance software.

We are particularly grateful to the members of the UVES Science Team B. Gustafsson (Uppsala Observatory), H. Hensberge (R.O.B., Brussels), P. Molaro (Osservatorio di Trieste) and P.E. Nissen (Aarhus University) for their advice and the support to the project throughout its development.

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VLT Pipeline Operation and Quality Control: FORS1 and ISAAC

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1. Introduction

It is well known in the community that April 1, 1999, marked the beginning of operations for ANTU, the first VLT telescope. It is less well known, however, that this date also marked the beginning of real life for VLT data-flow operations (DFO) at ESO Headquarters in Garching. Forming the back end of the Data-Flow life cycle, DFO has to act as data-production, data-distribution and data-storage machine. All these functions form what is called Quality Control (QC). For achieving data products of the highest possible quality, all components have to perform well and collaborate closely.

At the moment of writing this, two VLT instruments are operational: FORS1 and ISAAC, with the next two waiting at the front door (FORS2 and UVES). We will briefly describe in the following the different QC tasks for the two first VLT instruments.

2. General Functions

The most important tasks for QC Garching are:

- commission the instrument data-reduction pipeline,
- create master calibration data and calibration solutions,
- reduce science data,
- sort and distribute all kinds of data (raw, reduced, calibration, logs, listings) for the Service Mode package,
- check the quality of processed data,
- provide instrument health checks,
- perform trend analysis of quality parameters.

Present ESO strategy for processing and distributing data is as follows: calibration data are processed irrespective of the observing mode (both Visitor and Service Mode), science data are processed for Service Mode (SM) observing only. SM programmes (of supported instrument modes) receive a full set of raw, reduced and calibration data. Processed calibration data will become generally available as soon as the Archive storage project has been realised.

Hence a Visitor Mode (VM) night, from the QC point of view, requires only processing of calibration data, while a SM night needs the full machinery producing master calibration and reduced science files. For a typical 50:50 mix of SM/VM nights and an average QC fish[1] with 4-days-per-week duty, there is presently about one QC working day per ANTU operational night available. Any time more than that will produce a backlog.

[1]Since this process bears some resemblance to trout held in purification plant basins to indicate water quality, we have dubbed ourselves the 'QC fishes'.

3. FORS1

Data. Being a complex instrument with many different modes, FORS1 produces data from the very beginning of operations in a huge amount and variety. Period 63 produced about 24,000 raw FORS1 files – about 200 GB – , about half of them in Service Mode. 68.0% of all raw files were calibration data, 17.9% science data, the rest (12.7%) TEST data (acquisition, slit view, etc.). The vast majority of all FORS1 files (70.9%) was obtained in imaging mode (IMG), the second largest fraction (18.4%) in multi-object spectroscopy mode (MOS), 5.2% in long-slit spectroscopy (LSS), 3.9% in polarisation imaging (IPOL) or polarisation MOS (PMOS). Typically 100–200 files are produced per SM night which correspond to 1–1.5 GB of raw data resulting in another 1–1.5 GB of reduced data.

Pipeline operations. Due to the complexity of the task, we decided to start pipeline operations with the simplest modes, IMG and LSS. These together cover already 76% of all FORS1 data. Master calibration files routinely created are:

- Master BIAS files for all 4 CCD modes (high and low gain; 1-port and 4-port readout).
- Master flats for IMG mode: master SCREEN_FLAT_IMG, master SKY_FLAT, master NIGHT_FLAT. They come in two CCD modes (high and low gain, 4-port readout). Master SKY_FLATs are used for science reduction (see below) and hence are measured in all filters available for imaging, the most commonly used are the Bessell UBVRI filters. They are frequently measured in dusk *and* dawn.
- Tables with photometric zeropoints (ALIGNED_PHOTOMETRY_TABLE) from standard star frames for IMG mode: these are exposed in the five standard Bessell filters (UBVRI), usually in the high-gain, 4-port CCD mode. Sets of such five stan-