Heterodyne instruments will play an important role for observations from Chajnantor: APEX will be equipped with receivers covering all atmospheric windows from 200 GHz to 1 THz. In addition, several experimental receivers covering selected windows above 1 THz – uniquely observable from Chajnantor – will be provided. APEX will be equipped with autocorrelation spectrometers.

5. Site

The greatest problem for ground-based submillimetre astronomy is the absorption of incoming radiation by atmospheric lines, mainly by water vapour. This is why the submillimetre region of the spectrum is still relatively unexplored. Ground-based submillimetre astronomy can only be done from sites with extremely dry atmospheres, such as high mountain tops and in Antarctica.

Llano de Chajnantor is most likely the best place for submillimetre astronomy on Earth (possibly rivalled only by the far more inaccessible sites in Antarctica), because of its high altitude at 5000 m and also because of its location in the dry Chilean Atacama desert. Long-range monitoring to characterize the site for the ALMA project has been carried out since 1995, showing that the excellent atmospheric conditions on Cerro Chajnantor will allow observations in all submillimetre windows close to 50% of the time.

6. Infrastructure and operations

APEX will be operated as part of the La Silla Observatory. The staff of 18 will include astronomers, operators and engineers/technicians. There will be a base in San Pedro de Atacama (the nearest village at an altitude of 2500 m), which will consist of offices, laboratories, control room, cafeteria and dormitories, and the staff will sleep at the base. On the high site, APEX will be operated and maintained from a set of oxygenized and heated containers. Diesel generators will provide power, both at the base and at the high site. There will be a high-speed microwave link between the San Pedro base and the telescope, allowing APEX to be operated remotely from San Pedro in service mode and with flexible scheduling. There may also be a visitor mode with observations being done remotely from San Pedro. Part of the observing time will be dedicated to more experimental observations with PI instruments at THz frequencies.

7. Time scales

The antenna will be erected on the site in April 2003 by VERTEX Antennentechnik. At this time receivers operating at 90 GHz will be installed in order to do holography and to set the surface to 18 microns rms. First-light receivers will be installed soon after this, consisting of the SEST 1.3-mm receiver and perhaps also a single pixel bolometer. The first heterodyne receivers are expected to arrive at the end of 2003, and LABOCA, the 300 pixel bolometer array, in the beginning of 2004. APEX operations are expected to start in the beginning of 2004.

8. SEST and APEX

ESO and OSO are presently operating SEST on La Silla. In order to provide operational funds for APEX, SEST operations are expected to stop at the end of June 2003 and SEST will be closed. There is however a possibility that SEST may continue to be used after June 2003, by dedicated groups doing survey work.

More information on APEX can be found at: http://www.mpifr-bonn.mpg.de/div/mm/apex.html and http://www.oso.chalmers.se/oso/apex/index.html

VIMOS Commissioning on VLT-Melipal

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Introduction

In the mid-80s, multi-object spectroscopy (MOS) appeared as a new and powerful technique to perform the spectroscopy of many objects simultaneously. The idea is simple: instead of using a single slit as the input to a spectrograph, masks are manufactured with slits positioned facing the images of targets of interest in the entrance focal plane of the spectrograph. The technical implementation turned out to be more tricky, but the first successful experiments were conducted with punching machines, in particular at ESO and CFHT with the PUMA concept [1].

MOS was then quickly identified as the tool of choice to conduct deep galaxy surveys. Multi-object spectrographs on 4-m-class telescopes have been very powerful tools to quantify the evolution of galaxies over more than half of the age of the universe, up to redshifts ~1 [2][3]. This because the density of galaxies to I ~ 22 (reaching redshifts ~1 or about half the current age of the universe) projected on the sky is high enough that very efficient spectrographs with high-quality CCDs [4] can efficiently assemble samples of several hundreds of measured spectra and redshifts. The technique was then applied on the first 10-m Keck with the LRIS spectrograph [5] and produced most of the Lyman-break galaxies at redshifts 3–4 known today [6].

However, the study of galaxy evolution and of their space distribution over most of the age of the universe requires much more than the few thousand galaxies measured today, all surveys included. The need to study the distribution of galaxies in the local universe has prompted two major science and instrumentation programmes: the Sloan Digital Sky Survey (SDSS), and the 2dF Galaxy Redshift Survey. Both are acquiring several hundred thousands of galaxy spectra with dedicated MOS facilities [7][8]. Similarly, the need to acquire large numbers of spectra/redshifts over a redshift range 0–5 covering 90% of the current age of the universe, has been identified. This is required by the necessity to cover several time/redshift steps, study the evolution of various classes of galaxies in a wide range of environments, ranging from the low density of voids to very

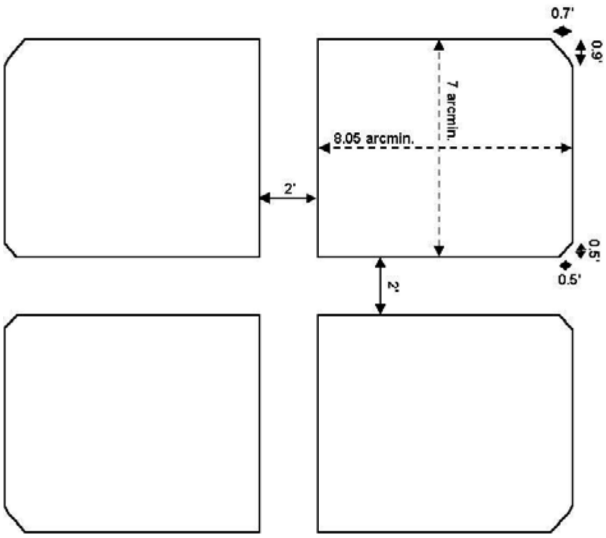

Figure 1: VIMOS field as projected on the sky, each quadrant has a field 7 × 8 arcmin², for a total field of 224 arcmin².

dense cluster cores. As an example, the measurement of the evolution of the luminosity function of galaxies or of the star-formation rate requires 50 galaxies per measured magnitude bin, over 10 magnitudes, for three basic types (colours) of galaxies, in three types of environments. Adding the necessity to probe several fields (i.e. 4) to minimize the impact of cosmic variance, and 7 time steps leads to a total galaxy sample of 50 × 10 × 3 × 3 × 4 × 7 = 126,000 galaxies. Very efficient MOS instruments are therefore needed.

In 1994, ESO convened a workshop to canvass the community in defining the full instrument complement for all unit telescopes of the VLT. A wide-field multi-object spectrograph appeared as the most important missing instrument in a poll of the community present at the meeting. Our team presented the baseline specifications and a tentative concept [9], the result of discussions across the community, in particular including the WFIS concept developed at ESO. A feasibility study was then commissioned by ESO to our consortium of French and Italian institutes, and conducted over 9 months in 1995–1996. ESO then issued a call for proposals to build a facility instrument, based on a wide-field MOS. The proposal presented by our consortium was selected by the ESO-STC in October 1996. A contract between ESO and the Centre National de la Recherche Scientifique of France represented by the then Laboratoire d'Astronomie Spatiale in Marseille (now Laboratoire d'Astrophysique de Marseille) was signed in July 1997, to construct VIMOS, the Visible Multi-Object Spectrograph, NIRMOS, the Near-IR Multi-Object Spectrograph, and the MMU, the Mask Manufacturing Machine.

After the successful completion of the Preliminary Acceptance Europe, VIMOS was shipped and reassembled in Paranal. We describe here the results of the main tests carried out during the first commissioning periods and present the general performance of VIMOS. This article is also intended to prepare the community to the arrival of this powerful facility.

VIMOS concept

VIMOS was designed from the outset to maximize the number of spectra observed with spectral resolutions R = 200–2500 (1 arcsec slits) [10]. The 4-channel concept allows one to maximize the multiplex gain: the field of view of each channel is 7 × 8 arcmin² in both imaging and MOS, projected on the central 2048 × 2350 pixels of a 2048 × 4096 pixels thin EEV CCD, while the full detector is used to record spectra. The slit sampling is set to allow Nyquist sampling for a 0.5 arcsec slit, with a plate scale of 0.205 arcsec/pix. In addition, the Integral Field Unit (IFU) covers a field 54 × 54 arcsec², with 6400 resolution elements 0.67 × 0.67 arcsec², each leading to a spectrum.

In all, it is really 4 instruments in one, with a total field of view of 224 arcmin², each channel being the equivalent of a complete FORS instrument. For each channel, a mask exchange unit (MEU), a filter exchange unit (FEU), and a grism exchange unit (GEU) permits configuration of the instrument in the imaging or MOS modes. Furthermore, special masks can be positioned at the entrance focal plane to configure the instrument in IFU mode.

To produce the masks placed at the VIMOS focal plane, a dedicated mask manufacturing unit (MMU) is available to cut masks with slits at any location, with any size and shape. It is fully described elsewhere [11]. The powerful laser machine is capable of cutting ~200 typical slits 1 × 12 arcsec each in less than 15 min. The MMU is also used to cut masks for the FORS2 MXU mode.

VIMOS observing modes

VIMOS has three main observing modes: direct imaging, multi-object spectroscopy with multi-slit masks, and integral field spectroscopy. The main characteristics of these modes are listed in Table 1.

Table 1: VIMOS observing modes

Imaging mode	
Field of view	4 × 7 × 8 arcmin²
Wavelength range	0.37–1 micron
Filters	U′ BVRIz
Spatial sampling	0.205 arcsec/pixel
Multi-Object Spectroscopy mode	
Field of view	4 × 7 × 8 arcmin²
Spatial sampling	0.205 arcsec/pixel
Low resolution R ~ 200 (1 arcsec slit)	Grisms: LRBlue
Number of slits ~1000 of length ~8 arcsec	LROra
	LRRed
Medium resolution R ~1000 (1 arcsec slit)	Grisms: MR
Number of slits ~400 of length ~8 arcsec	
High resolution (1 arcsec slit)	Grisms: HRBlue
Number of slits ~200 of length ~8 arcsec	HROra
	HRRed
Integral Field Spectroscopy mode	
Field of view	54 × 54 arcsec²
Wavelength range	0.37–1 micron
Spatial sampling	0.67 arcsec / fiber
Number of resolution elements / spectra	6400
Spectral resolution	R ~ 200–2500

Figure 2: Installation of VIMOS on the VLT-UT3. From upper left, clockwise: (a) transportation of VIMOS from the Paranal Observatory integration facility to the telescope, (b) VIMOS being hoisted inside the dome of Melipal to reach the Nasmyth platform, (c) installation on the Nasmyth rotator, (d) VIMOS after cabling and co-rotator installation.

VIMOS integration and tests

After completing integration and testing at the European integration facility at Observatoire de Haute-Provence, France, VIMOS was completely disassembled and shipped in more than 50 crates (a total of 15 tons) at the end of 2001. The reassembly took place in the integration facility of the Paranal Observatory in January-February 2002. Optical alignment was checked, all mechanical motions were tuned and verified over hundreds of cycles, and all software components were implemented prior to the installation at the telescope. The instrument was moved to Melipal on February 23rd (Figure 2). VIMOS is now attached to the Nasmyth focus B of the “Melipal” – UT3 telescope of the ESO Very Large Telescope (Figure 2).

The weight of the instrument turned out to be significantly larger than foreseen in the original design. At a total weight of 4 tons, VIMOS is about 1 ton overweight with respect to the Nasmyth rotator-adapter specification. It was necessary to implement a support structure at the back end of the instrument to relieve the adapter from the extra weight as seen in Figure 3.

In a first commissioning run in February 2002, the first 2 channels were extensively tested on the sky. While the internal image quality was measured to conform to specifications during integration, images on the sky have demonstrated the excellent overall image quality of the combined telescope + instrument. Images as good as 0.4 arcsec FWHM have been recorded. The complex sequence necessary to place slits at the focal plane in coincidence with selected targets, involving a transformation matrix from sky to mask focal plane to detector, has been tested and validated.

In a second technical commissioning in May 2002, the support structure to compensate the extra weight was installed, and the 4 channels completely integrated. Due to bad weather, many calibration tests were obtained on the complete 4-channel configuration but no sky observations could be obtained. Image and spectral quality have been confirmed to be within specifications.

After technical activities in July 2002, completing the work on the support leg and on flexures adjustment, VIMOS will have its third and last commissioning on the sky in September 2002.

VIMOS performance

Image quality

The image quality of the optical train was measured for each channel. A grid with pinholes 100 microns in diameter was produced with the Mask Manufacturing Unit and placed at the entrance focal plane. The optical alignment was perfected by means of a relative X,Y adjustment of the last element of the optical train coupled to the detector assembly. All channels are fully in specification, with 90% of the field with images better than 0.5 arcsec at 80% encircled energy as shown in Figure 4.

Flexure

Flexure control for a 4-ton instrument has been a concern from the start of the project. The main VIMOS structure was designed to minimize flexure defined as

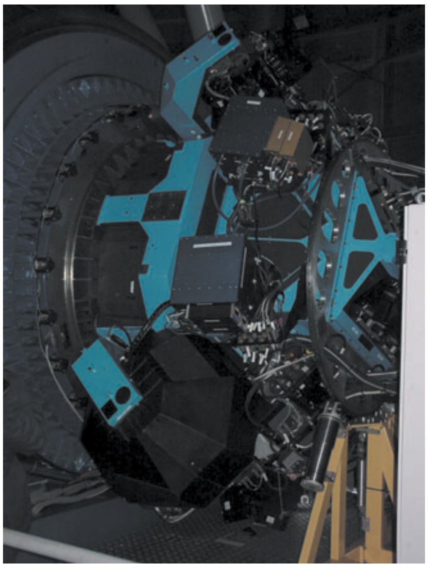

Figure 3: The fully integrated instrument on the Nasmyth focus, including its dedicated support structure to the right.

motion on the CCDs of a light spot produced at the entrance focal plane. A mechanical support system was implemented at the back of the folding mirrors on the optical train to allow for passive flexure compensation by means of astatic levers. This support system can also be upgraded to an active support using piezo-actuators to apply motion on the folding mirrors to compensate for flexure.

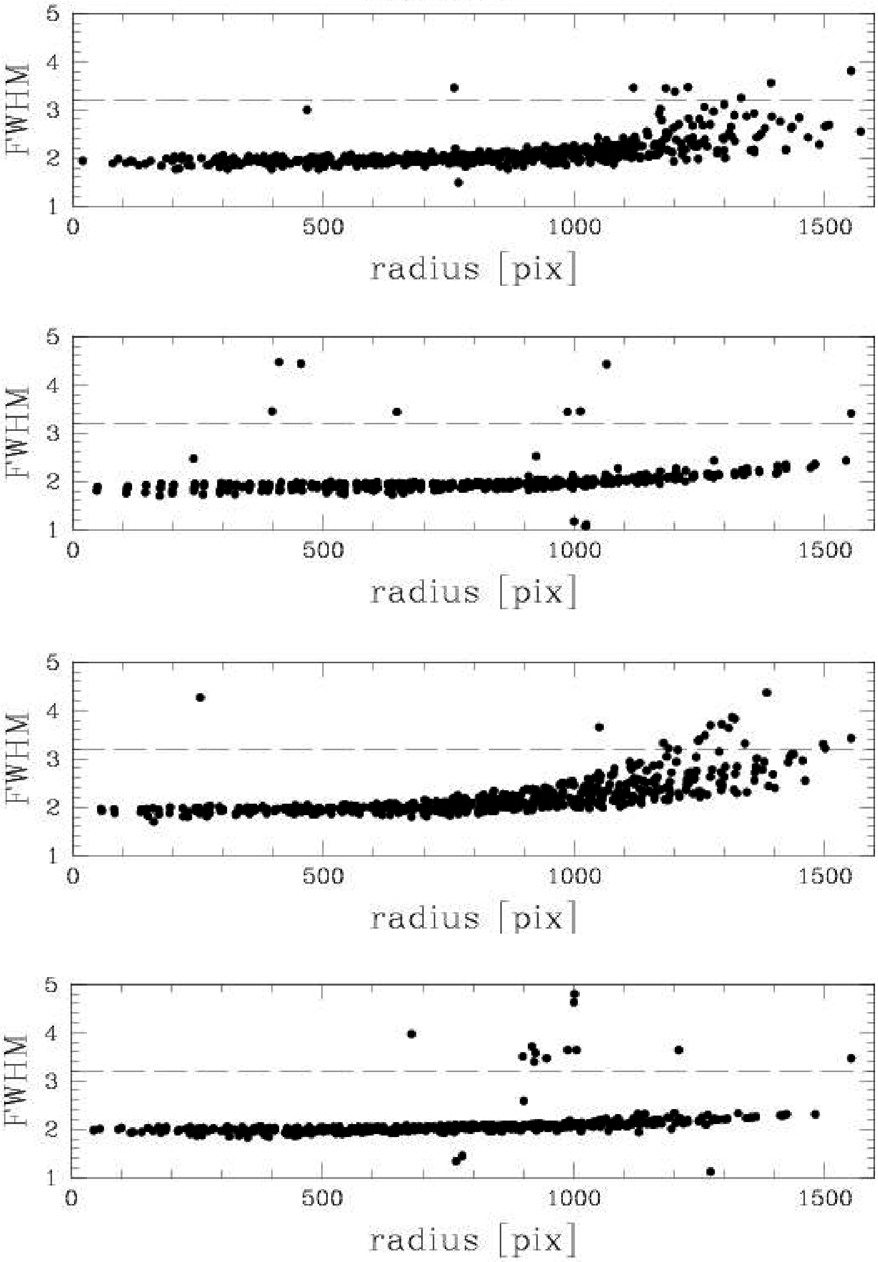

Figure 4: image quality as a function of radius from the field centre, measured for channels 1 to 4 (top to bottom) on a grid of pinholes 300 microns in diameter. The image quality is better than the specification identified by the dashed line. ►

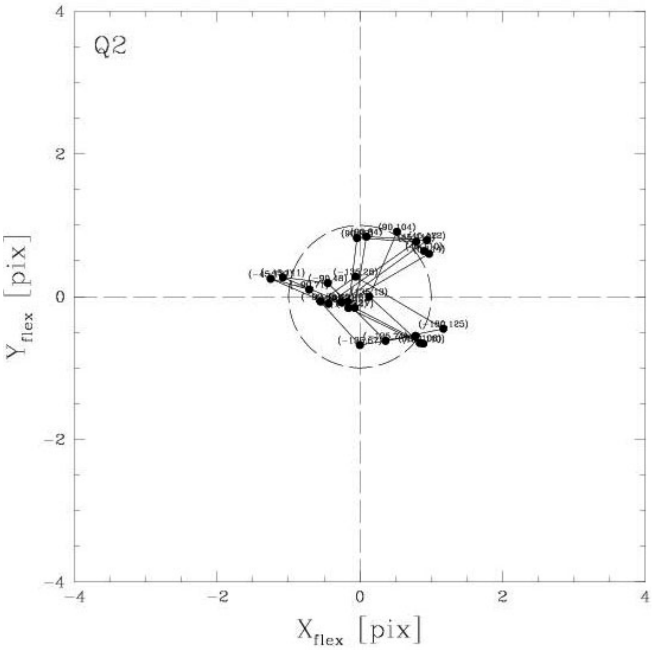

Figure 5: Flexure measurement on channel 2. The points represent the position of a reference spot of light on the detector, as a function of the rotation angle of the Nasmyth rotator over 360°. The dashed circle represents a 1-arcsec radius motion of the reference spot.

Uncompensated flexure is measured to be on order ± 2.5 pixels in both X (along slit) and Y (dispersion) for a full 360° rotation of the instrument. Astatic levers have been installed and are being adjusted at the time of this writing. They are expected to cut the flexure by a factor 3, as based on previous measurements taken during integration at Haute-Provence Observatory. This is shown on the current corrected flexure behaviour for channel 2, showing flexure contained within a one-pixel radius (Figure 5). Optimization of the other channels is under way.

VIMOS first light

First light was achieved on February 26, 2002, with VIMOS in 2-channel mode. Images with excellent image quality were recorded right away (see e.g. Figure 6 to Figure 8, and images on http://www.astrsp-mrs.fr/virmos

Table 2: Photometric zero points

Filter	Zero point (preliminary, average of 2 channels) Mag = zero point –2.5 log (flux) in ADU) –2.5 log (CCD gain) +2.5 log (exposure time)-kc.sec (air mass)
U	26.3
B	28.0
V	27.7
R	27.8
I	27.0

Figure 6: Image of the "Antennae" taken during the first night of VIMOS on the sky. Composite of V, R, and I images, 60 seconds each. The image quality measured on stars is 0.6 arcsec FWHM.

Imaging performance

The overall throughput of the instrument can be measured in terms of the photometric zero points used to transform the observed CCD counts to magnitudes as listed in Table 2. This is better in the UV and blue than the comparable FORS instrument on the VLT and shows equivalent sensitivity in the visual-red, when the additional reflection in the telescope is taken into account.

Multi-object spectroscopy performance

Masks have been produced from images taken with the instrument. The transformation matrix from CCD to mask was computed using images from a uniformly distributed grid of pinholes. This transformation proved to be very accurate: from the first try onward, slits and reference apertures on masks have been successfully positioned directly on top of astronomical objects.

Examples of masks observed are shown in Figure 9. This demonstrates the great multiplex capability of VIMOS, with several hundred objects being observed simultaneously. The details presented in Figure 10 show the high accuracy of the slit profile, thanks to the high precision of the laser-based mask manufacturing unit [11].

The mask design interface allows one to define a mask in an automated fashion from a "pre-image" taken with VIMOS. Slits can be placed either on targets selected from a catalogue of objects detected on the pre-image, or on objects from a user imported catalogue. The software cross correlates the brightest objects detected in the pre-image with objects in the user catalogue to define a transformation matrix. This allows one for instance to use very deep images taken with VIMOS or another facility to place slits on objects not visible on the short-exposure pre-images. Slits are placed in an automated fashion in order to maximize the number of objects, and to minimize the effect of overlap between orders when working with several banks of spectra along the dispersion direction.

Performance in spectroscopy mode is as expected, and follows the computations from the Exposure Time Calculator (see ESO web page referred to below). Spectra of extended $I_{AB} \leq 22.5$ galaxies have been recorded in 3 × 15 min exposures, with S/N ~ 5–10 on the continuum (Figure 14).

Spectra with the integral field unit have also been obtained as shown in Figure 11.

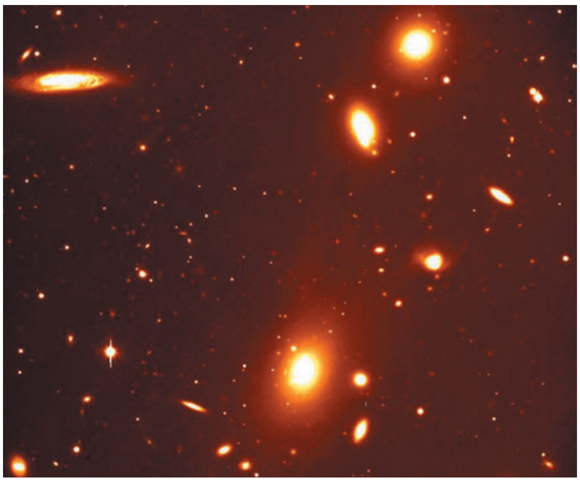

Figure 7: image of the cluster of galaxies ACO 3341.

Figure 8: Central part of the cluster Cl 1008-12. Composite of V, R, and I band exposures, 5 minutes each.

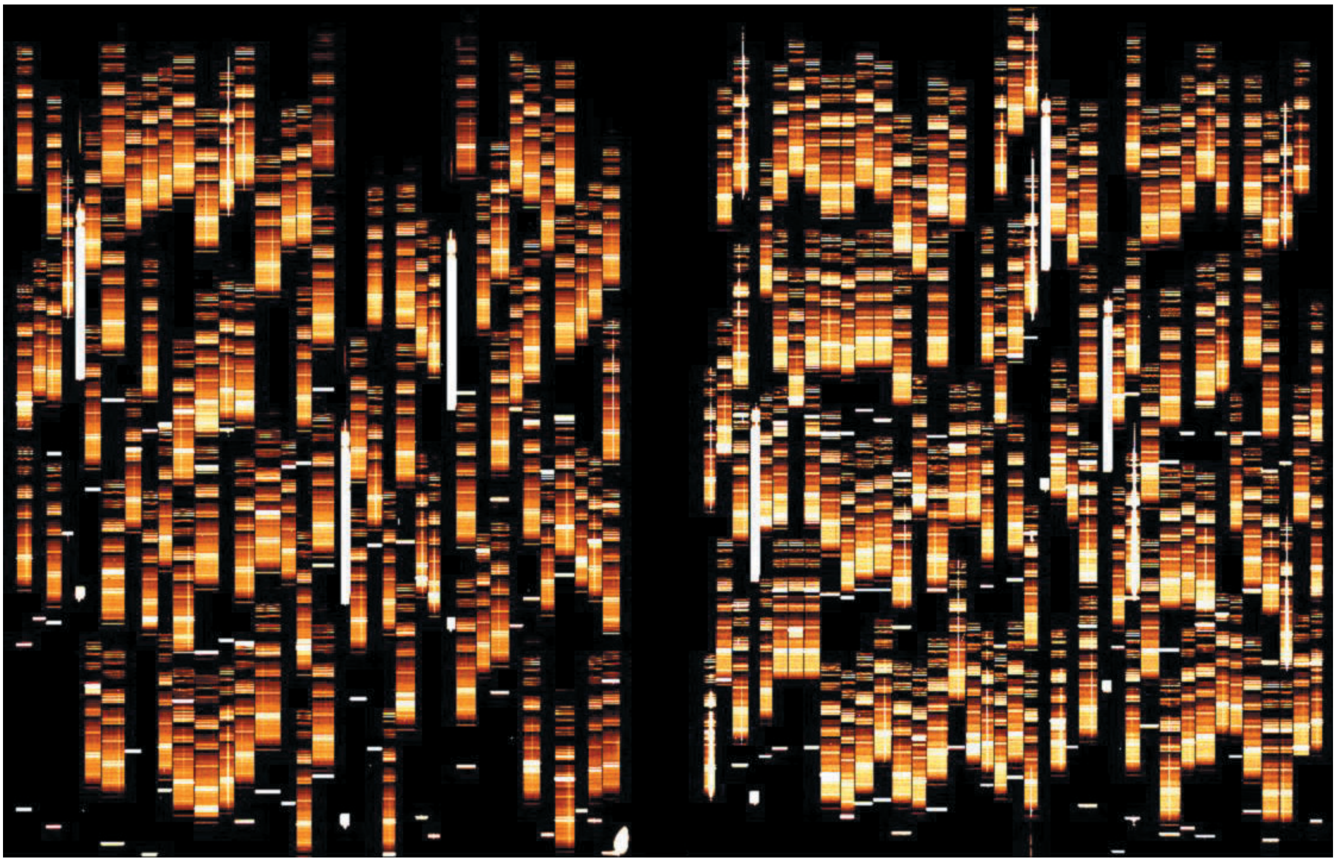

Figure 9: Example of multi-slit data taken with VIMOS during the first light in February 2002. In these masks on 2 channels, more than 220 objects were observed simultaneously with a spectral resolution R ~ 250.

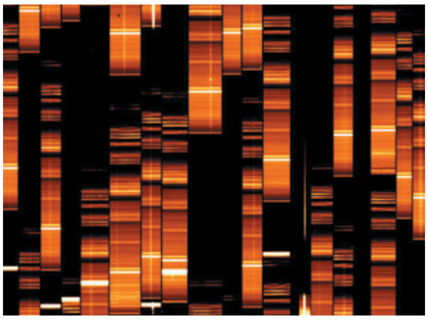

Figure 10: Detail of a raw MOS spectra frame. One can identify the trace of the continuum of galaxies in each slit. The slit profile is extremely accurate thanks to the high precision of the MMU. Fringing from the detector is visible in the red part of the spectra (towards the top).

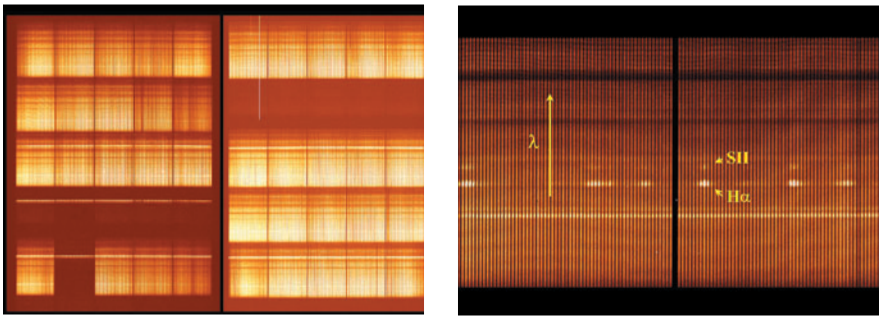

Figure 11: Spectra taken with the VIMOS-IFU. Left: 3200 spectra obtained with 2 channels in February 2002. Right: enlarged portion of the IFU spectra showing the emission lines from a planetary nebula observed during tests.

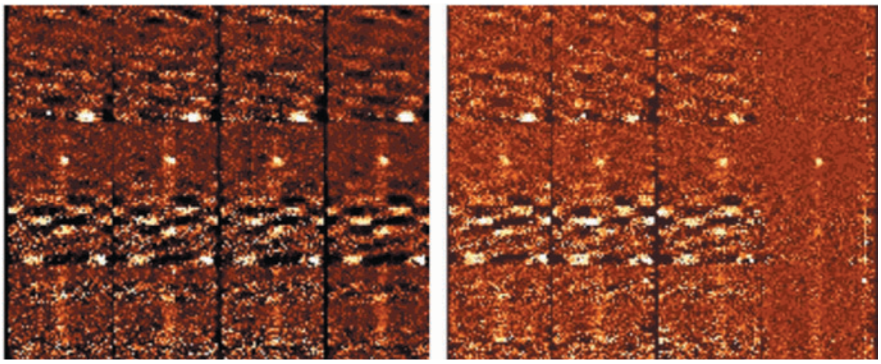

Figure 12: Processing of the VIMOS MOS data. Left panel: *sequence of 3 spectra taken while the object was maintained at the same position in the slit. Three sky-subtracted spectra are shown from left to right (about 200 Å around 8200 Å; wavelength increases towards the top), together with the combined average of the three spectra on the right. Significant fringing residuals are present.* Right panel: *in this set of observations, the object was moved along the slit at positions –1, 0, +1 arcsec; the combined average shows that fringes can be corrected to a high level of accuracy.*

Data processing

Spectra have been processed using dedicated Data Reduction Software (DRS). The spectra are corrected for the detector response and the sky lines are subtracted before the 2D spectra are summed. The 1D extraction then follows, with wavelength and flux calibration. Because of the thin substrate of the EEV detectors, fringing from the strong sky OH emission appears above ~ 8200 Å. This fringing can be efficiently removed using a sequence of shifts of objects along slits, as shown in Figures 12 and 13. Spectra of extended galaxies with $I_{AB} \leq 22.5$ are shown in Figure 14.

Summary

The wide-field survey instrument VIMOS is now being commissioned at the VLT. In each of the three operational modes (imaging, multi-slit spectroscopy and integral-field spectroscopy), VIMOS offers an unprecedented field of view. In multi-slit spectroscopy mode, several hundred spectra can be recorded simultaneously, while in integral-field mode, 6400 spectra are recorded in a field 54 × 54 arcsec^2. It is expected that VIMOS guest observations will start in April 2003. Information needed to prepare observing proposals is available on the web pages http://www.eso.org/instruments/vimos/index.html

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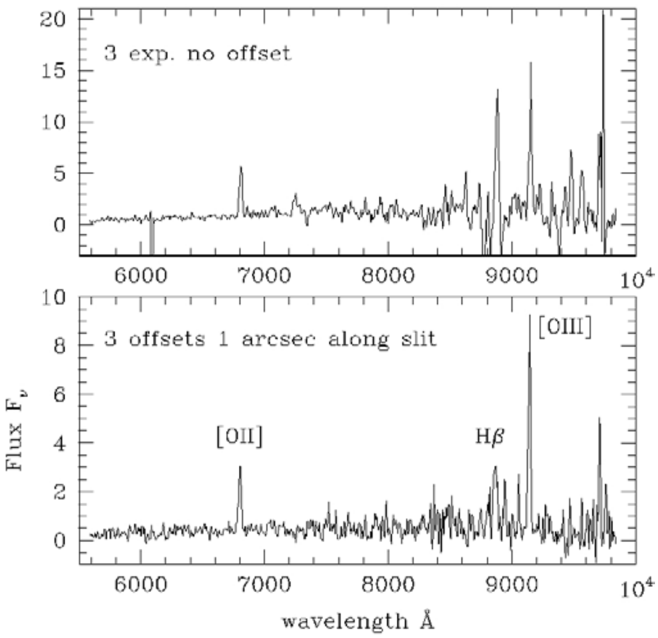

Figure 13: Effect of sky and fringe subtraction with (bottom) and without (top) shifting objects along the slit as described in Figure 12.

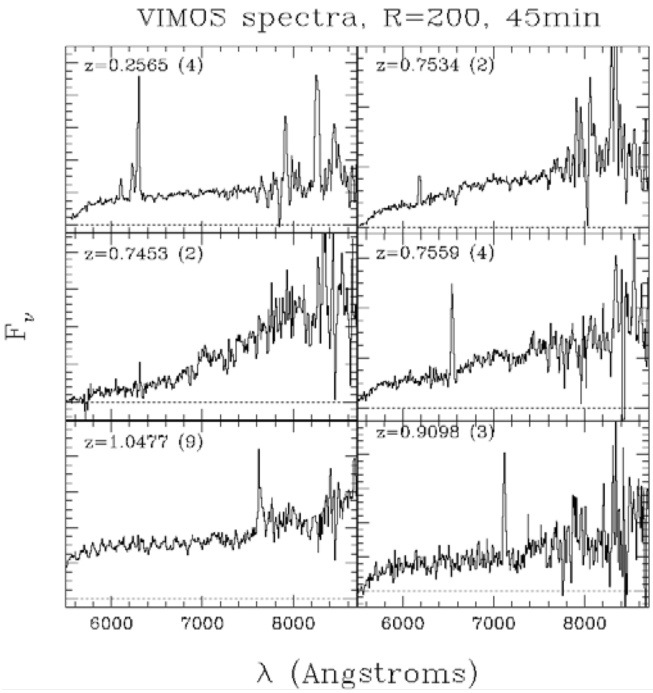

Figure 14: Examples of spectra taken with VIMOS during the first commissioning in February 2002. The redshift is indicated in the upper left corner of each panel. These spectra are the average of 5 exposures 10 minutes each with the LR grism (R ~ 200).

2.2-m Team

L. GERMANY

Welcome to the last (very short) installment of 2p2team news from La Silla. This is mostly just a farewell message, as in October we cease to operate as a separate entity and join with the old NTT and 3.6 teams under the new guise of Sci-Ops. Never fear though, the next *Messenger* will see this section expanded to include all the telescopes and instruments on La Silla.

The folding of the 2p2team heralds the end of ESO time at both the ESO 1.52 and Danish 1.54-m telescopes. The Boller and Chivens spectrograph is only available in Brazilian time until the end of 2002, after which time the instrument will be mothballed and the telescope decomissioned. FEROS is moving to the 2.2-m telescope at the end of Period 69 and we expect it to be up and running in its new home by November 2002. The Danish telescope will continue to operate after October 2002, but only in Danish time.

So farewell from the 2p2team and we'll see you next time as Sci-Ops.