The VIMOS and NIRMOS multi-object spectrographs for the ESO-VLT

O. Le Fèvre [a], M. Saisse [a], D. Mancini [d], G. Vettolani [b], D. Maccagni [c], J.P. Picat [e], Y. Mellier [f], A. Mazure [a], J.G. Cuby [g], B. Delabre [g], B. Garilli [c], L. Hill [h], E. Prieto [a], C. Voet [a], L. Arnold[h], S. Brau-Nogué [e], E. Cascone [d], P. Conconi[i], G. Finger [g], G. Huster [g], A. Laloge [a], C. Lucuix [e], E. Mattaini[c], P. Schipani [d], G. Waultier [a], F. Zerbi [i], G. Avila [g], J. Beletic [g], S. d'Odorico [g], A. Moorwood [g], G. Monnet [g], J. Reyes [g]

[a] Laboratoire d'Astronomie Spatiale – CNRS, B.P.8, F-13376, Marseille Cedex 12, France
[b] Istituto di Radio Astronomia - CNR, Via Gobetti, 101, I-40129 Bologna, Italy
[c] IFCTR - CNR, Via Bassini, 15, I-20133, Milan, Italy
[d] Osservatorio Astronomico di Capodimonte, Via Moiariello, 16, I-80131, Naples, Italy
[e] Observatoire Midi-Pyrénées, 14 Av. Ed. Belin, F-31400 Toulouse, France
[f] Institut d'Astrophysique de Paris, 98bis Bvd. Arago, 75014 Paris, France
[g] European Southern Observatory, Karl-Schwarzschild-Str.2, D-85748 Garching, Germany
[h] Observatoire de Haute Provence, F-04870 St. Michel, France
[i] Osservatorio Astronomico di Brera, Via Bianchi, I-22055 Merate, Italy

ABSTRACT

The VIRMOS consortium of French and Italian Institutes is manufacturing 2 wide field imaging multi-object spectrographs for the European Southern Observatory Very Large Telescope, with emphasis on the ability to carry over spectroscopic surveys of large numbers of sources. The VIsible Multi-Object Spectrograph, VIMOS, is covering the 0.37 to 1 micron wavelength domain, with a full field of view of 4×7×8 arcmin² in imaging and MOS mode. The Near InfraRed Multi-Object Spectrograph, NIRMOS, is covering the 0.9 to 1.8 microns wavelength range, with a field of view 4×6×8 arcmin² in MOS mode. The spectral resolution for both instruments can reach up to R=5000 for a 0.5 arcsec wide slit. Multi-slit masks are produced by a dedicated Mask Manufacturing Machine cutting through thin Invar sheets and capable of producing 4 slit masks ~300×300mm each with ~200 slits 5.7mm long (10 arcsec) in less than one hour. Integral field spectroscopy is made possible in VIMOS by switching in the beam specially build masks fed by 6400 fibers coming from a 54x54 arcsec² integral field head with a 80×80 array of silica micro-lenses. NIRMOS has a similar IFS unit with a field of 30×30 arcmin². These instruments are designed to offer very large multiplexing capabilities. In MOS mode, about 1000 objects can be observed simultaneously with VIMOS, with a S/N=10 obtained on galaxies with I=24 in one hour, and ~200 objects can be observed simultaneously with NIRMOS, with a S/N=10 obtained on galaxies with J=22, H=20.6 in 1h at R_{eq}=200 (R_{obs}=2500). We present here the status of VIMOS, currently under final integration, with expected first light in the summer 2000, together with the final design of NIRMOS presented at the Final Design Review. The VLT-VIRMOS deep redshift survey of more than 150000 galaxies over the redshift range 0<z<5 will be undertaken based on 120 guaranteed nights awarded to the project.

Keywords: Multi-object spectroscopy, integral field spectroscopy, spectroscopy, astronomy, fiber technology

1. INTRODUCTION

Multi-object spectrographs are a key element into the instrument complement of a modern observatory. Only 10 years ago, these instruments were only prototypes delivering the first scientific results on deep redshift surveys. Since then, many facilities have appeared and allow to conduct e.g. the large redshift surveys at redshifts up to about 4 [1,2,3,4]. On the new generation of 8-10m telescopes, several advanced multi-object spectrographs are under development [5,6,7].

The VIRMOS project has been approved by ESO in December 1996, to provide the European community with two highly efficient multi-object spectrographs covering together the wavelength range 0.37 to 1.8 microns. The main thrust is to be able to carry out spectroscopic surveys of large numbers of objects, in particular faint galaxies. The project has been identified as "fast track", with the shortest development time yet applied to instruments of this size and complexity. From the decision date to launch the project, to the first light of VIMOS at Paranal, less than 3.5 years will have elapsed. A "success oriented" approach to project management has been applied, in which risk management and minimum buffer time allocation is playing a crucial role.

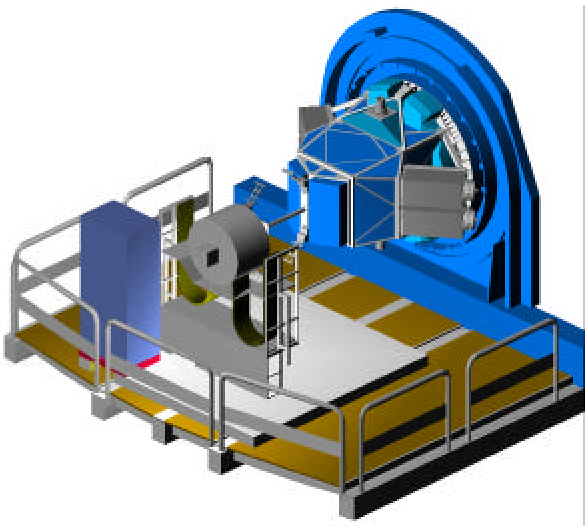
The VIMOS spectrograph is now in integration phase in the specially build integration facility at Observatoire de Haute Provence, with most of the sub-systems completed. It will be shipped in the spring of 2000, with first light in the summer. The NIRMOS spectrograph is going through its final design review, and manufacturing should start in the next weeks. It is expected to deliver NIRMOS in the fall of 2001. This paper presents a gallery of picture from VIMOS in its current manufacturing, and the NIRMOS final design.

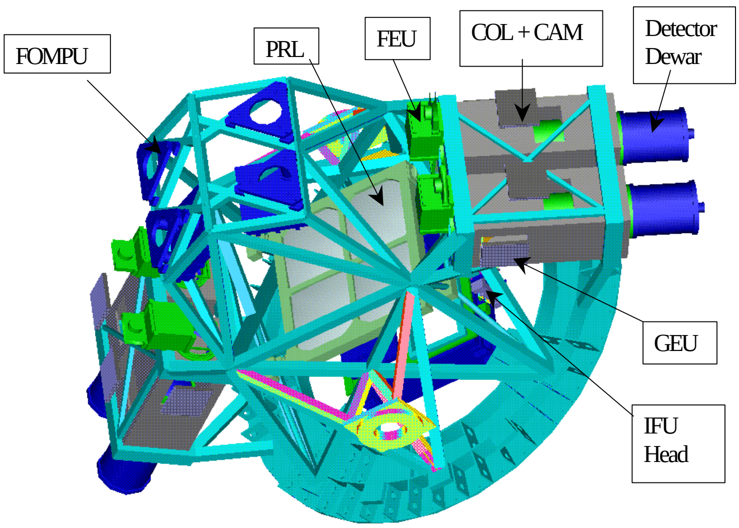
More details can be found at `http://www.astrsp-mrs.fr/www_root/projets/virmos/virmos-top.htm`

2. VIMOS: THE VISIBLE MULTI-OBJECT SPECTROGRAPH

2.1 Overview

VIMOS will be installed on the VLT unit no.3 . It is a 4 channel imaging spectrograph, each channel with a field of 7×8 arcmin². Spectral resolutions from R~200 to R~5000 are available. Close to 1000 and 200 spectra can be observed simultaneously at low and high spectral resolution respectively, and a full 54×54 arcsec² field can be observed with the integral field spectroscopy mode. All optical elements have been manufactured within the specifications. Most sub-systems are already manufactured, or in the final manufacturing phases. See Le Fèvre et al.[7] for more details on the general concept and opto-mechanical design.





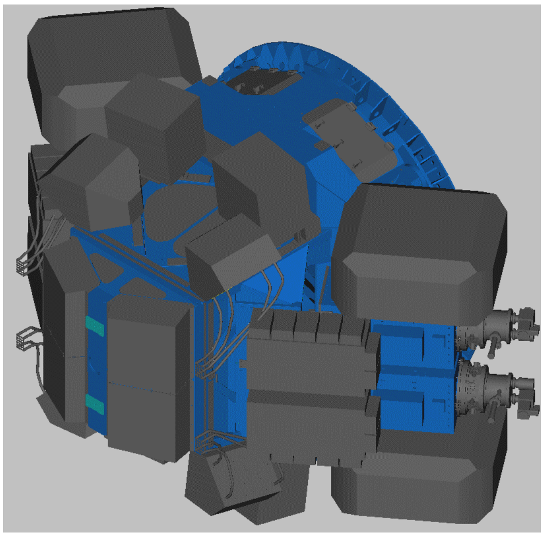


Figure 1: VIMOS overview on the Nasmyth plateform with the co-rotator (top right), main subsystems (bottom left), general view (bottom right)

2.2 Main Optical Train

The VIMOS optical design has been presented in Le Fèvre et al. [7] . The baseline concept is to have 4 identical channels next to each other and supported by the same mechanical structure. Each optical channel is a classical focal reducer imaging spectrograph, with a collimator, a parallel beam where dispersive elements, grisms, are inserted, followed by a camera focussing onto a 2048×4096, 15 microns pixels CCD. The field delivered by the telescope is flattened by a field lens to allow for flat multi-slit masks. This Focal Plane Adaptation Lens (FPAL) is made of an air-spaced doublet of Ohara SFL5 glass, and has proven to be one of the most complex optical element to manufacture, with pronounced surface curvature as seen in Figure 2. The final FPAL is shown in Figure 3.

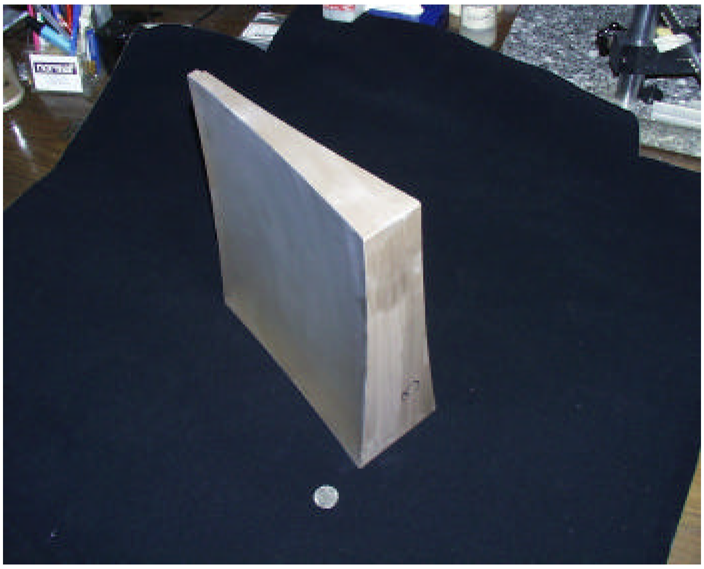


Figure 2: one of the 2 elements of the Focal Plane Adaptation lens, made from Ohara-SFL5 glass

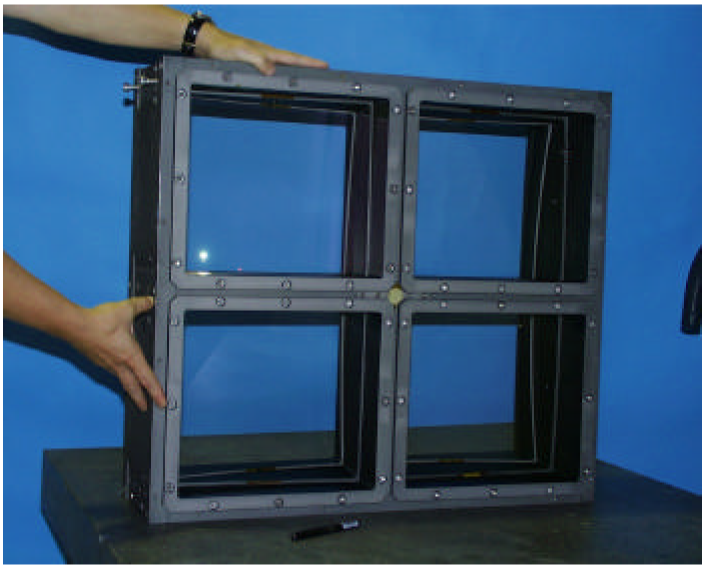


Figure 3: The final FPAL

Figure 4: the VIMOS collimator, with the Pupil Relay Lens (left) with overall dimensions 830x760mm, and the 4 last doublets of the collimator in their mounts (right)

The first part of the collimator, the Pupil Relay Lens (PRL) is a relatively large element made of a glued doublet of Ohara SFSL5 and Schott F2 to correct for pupil chromatism in combination with the FPAL (Figure 4). A folding mirror is inserted in the collimator to fold the beam and reduce the instrument overall dimensions and moment. The last part of the collimator is an air-spaced doublet of a K5 negative lens and a CaF2 positive lens (Figure 4).

Each of the four cameras is a complex yet efficient combination of 8 lenses in 4 blocks (see ref. 7), with a total weight of 30kg. The first group is made of 4 cemented lenses (FK54-LF5-K5-FK54), the most critical to manufacture of this design (Figure 5). The second and the third blocks are converging lenses made of FK54 and CaF2. The last surface of the CaF2 lens is aspheric, diamond-turned and post polished. The last block is used as the cryostat window and is a SF5-Silica doublet (Figure 5).

All optical elements have been manufactured following tight specifications by SESO (Aix, France).

Figure 5: The VIMOS cameras, *(left)* combination CAM+CWL being tested at SESO (Aix, France), *(right)* three of the cameras and CWLs, each camera+barrel weights 30kg.

2.2 Filters and Gratings

Up to 10 filters can be loaded in each of the 4 filter exchange units. The standard set of UBVRIz multi-layer coatings filters are 170mm in diameter. Peak transmissions of 90to 95% have been achieved by Barr Ass. for these broad band filters.

Gratings are classical grisms, with a ruling replica on resin deposited on a prism. Some grisms are replica of existing master gratings, while new masters had to be manufactured for some. The list of VIMOS grisms is given in Table 1. Most of the grisms have already been manufactured by Richardson Grating labs (Rochester NY, USA), while several items have yet to be delivered. Order sorting filter are used to avoid overlap between the 1st and second grating order.

Table 1: List of VIMOS grisms

Grism #	LR1	LR2	HR1	HR2	HR3	6
	LowRed	LowBlue	HigRed	HigBlu	HigOra	Interm
Dimensions (Cm)	17x16x3	17x16x3	17x16x18	17x16x18	17x16x18	17x16x6
Beam ∅ (Cm)	14	14	14	14	14	14
glass	F2	BK7	F2	BK7	K5	BK7
resin	REG	UV	REG	UV	UV	UV
glass index	1.6103	1.5314	1.610	1.521	1.521	1.514

resin index	1.5812	1.5409	1.582	1.529	1.521	1.524
prism angle	5.3	5.3	46.6	44.8	46.7	16
blaze angle	4.3	4.6	49	43	49	15
grooves/mm	75	100	600	720	600	200
central λ	751	482	740	510	631	708
blaze λ	581	396	732	500	631	680
Rec. Dispersion	485	353	40.2	33.9	40.5	171
resolution R	211	183	2520	2050	2150	580
Richardson's catalogue	3553750	n.e.	3553570	n.e.	3553570	3563630
central λ range	550-950	370-670	630-870	415-620	520-760	500-1000
right λ range (3.5')	550-950	370-670	570-805	370-566	463-703	500-950
left λ range (3.5')	550-950	370-670	690-930	468-674	577-817	500-1000
multiplex	4/5	4/5				2
coating (µ MgF2)	0.110	0.080	0.135	0.080	0.110	0.110
tilt	7.0	7.0	2.4	3.2	2.4	7.0
order sorting	Barr F. 1	Barr f. 2	GG475	NO	GG435	Barr F.1
Thick. O.S. Filter	12mm	12mm	12mm		12mm	12mm

2.3 Main structure

The main structure is assembled from fully welded serrurier trusses to provide stability of the main opto-mechanical sub-components over 360° rotation on the Nasmyth rotator. The finite element analysis shows that the optical beam on the detectors should not move by more than 4 microns (0.05 arcsec) over all rotation angles.

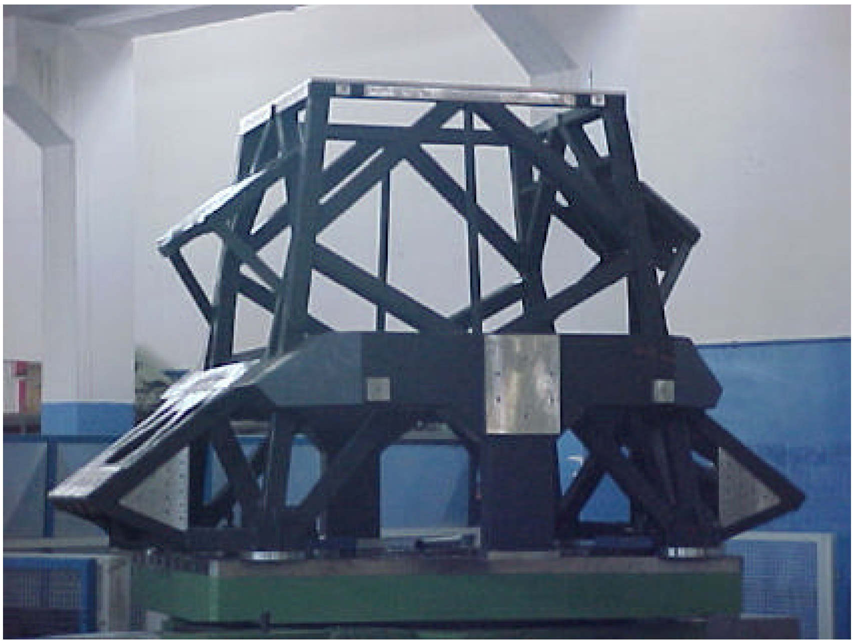


Figure 6: the VIMOS main structure, (left) baseplate interface to the Nasmyth rotator, (right) the main structure serrurier trusses.

Figure 7: VIMOS main structure installed on the VIRMOS test stand in the integration facility at Haute Provence Observatory

2.4 Main sub-systems

The main sub-systems along the optical path are (Figure 8 to Figure 11):

- The mask focal plane and mask exchange mechanism. The stability of the masks in the focal plane is better than 12 microns over a 180° rotation of the instrument. Four mask cabinets make available 15 masks for observations.
- The folding mirror unit. It holds the 4 mirrors. In case flexures are larger than 1/4 of a pixel on the detector as computed from finite element analysis, piezo-electric actuators can be installed in each of the mirror support for active tip-tilt control. This will be decided in the next weeks as overall flexure measurements become available.
- The optical box and grisms exchange unit. This unit includes the last elements of the collimator, the grisms and grisms exchange mechanism, the camera and focussing unit, and the CCD cryostat
- The co-rotator. It is used to co-rotate all power, control and cooling lines toward the instrument, from the Nasmyth platform. It is a clone of the ISAAC co-rotator developed by ESO, manufactured by the VIRMOS consortium

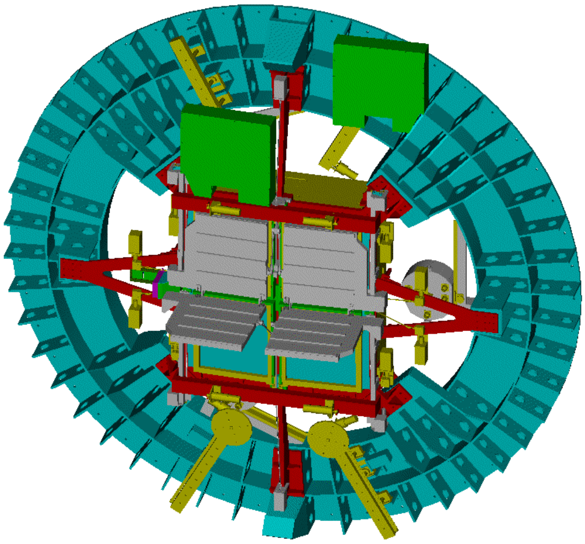


Figure 8: The mask focal plane and mask exchange mechanism

Figure 9: the VIMOS co-rotator

Figure 10: the VIMOS "optical box"

Figure 11: the Folding mirror unit. The 3 cylinders seen on the right are designed to house piezo-actuators for active tip-tilt control of the mirrors

2.5 Control Hardware

Each of the 4 channels has the following subsystems to be controlled: Mask Exchange Unit (MEU), Mask Shutters (MS), Filter Exchange Unit (FEU), Grism Exchange Unit (GEU), Focusing Unit (FU), Integral Field Unit (IFU), Folding Mirror Positioning Unit (FOMPU), Calibration Unit (CU). The following is installed in a single configuration, IFU Elongator and IFU Shutter

The equipment has been chosen in conformity with ESO VLT instrumentation standards, in order to ensure compatibility with other ESO instruments and simplify maintenance and integration in the VLT environment. The VLT control system is based on a distributed network of VME-based local Control Units (LCUs), that manage the real time control, while a higher level of Unix based Workstation manage the user interface, the co-ordination, testing and maintenance.

The standard VLT LCU is based on a stand-alone VME crate equipped with a Motorola CPU board, Ethernet board, and real time operating system VxWorks. Starting from this standard base, each LCU is equipped with an assortment of control and interface board, depending on the specific functions.

Successful control of the first sub-systems (FEU, FU) has occured in January 2000.

2.6 Software

The Instrument Software is to operate the instrument, to test and maintain it, to prepare observations and to reduce the obtained data. Each of these tasks has its own dedicated software package, with its own maintenance capabilities and testing mode, its own Graphical User's Interfaces and can be operated as a stand alone system.

Observation Preparation Software : includes all tasks needed by the user to prepare observations. It includes the template signatures needed by P2PP package to build the Observation Blocks, template scripts and the Exposure Time Calculator (ETC).

Mask Preparation Software: the main task of MPS is to allow the astronomer to choose the objects onto which to position the slits and control the slit cutting process. It shall also take care of keeping a log of the available masks for use by the OS. The astronomer-dedicated part (object selection, MPS_P2PP) will be developed in the MIDAS environment and run at proposal PI premises. The second part (conversion from celestial to machine coordinates and control of the slit cutting process, MPS_IWS) will reside on the Instrument Workstation.

Observation Software : OS handles the single observations. It sends commands to the appropriate subsystems, receive acknowledge by them, handle observation sequences. It will also take care of coordinating operations between ICS and DCS, and TCS.

Instrument Control Software : ICS subsystem controls all hardware motions through the LCUs.

Device Test Software : DTS is developed for direct hardware control. It includes all the low level meta-libraries, eventually required by ICS to control motors.

Detector Control Software : DCS must be capable of controlling the four detectors associated to VIMOS. As in VIMOS there are four detectors to be operated simultaneously and in the same configuration, there are two DCS, the coordination of which is a task for OS.
Data Reduction Software : Data Reduction Software allows the user to take out instrument signature from his/her data and to extract astronomically meaningful information from the data. It consists of on-line pipelines to be carried out at Paranal, and off-line calibration and observatory pipelines, to be carried out in Garching.

Full computer control of the first sub-systems FEU and FU has happened in January 2000.

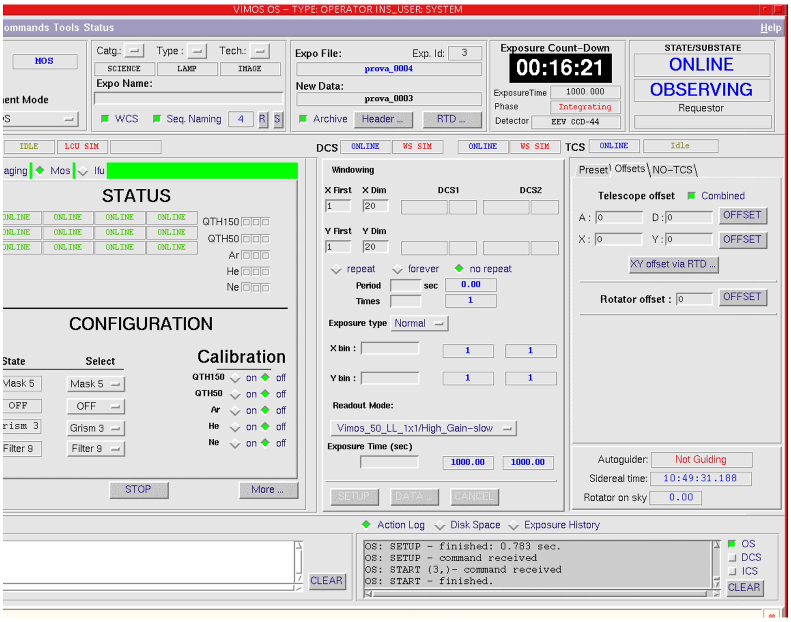


Figure 12: VIMOS Observation Software Panel

2.8 Detectors

The detectors and control electronics have been produced by the ESO optical detectors team. There are four complete detector units, each unit including a 2048×4096, EEV 44-82, backside illuminated, single layer AR coated CCD, with 15 microns pixels. The readout noise performances range from 3.5 to 5.5 electrons.

Figure 13: one of the 4 VIMOS CCD heads

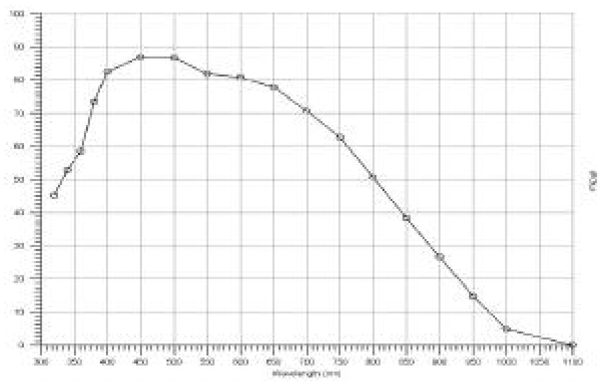


Figure 14: A typical quantum efficiency curve of one of the VIMOS CCDs

3. THE VIMOS INTEGRAL FIELD UNIT

See Prieto et al. [8], this volume for a full description of this system.

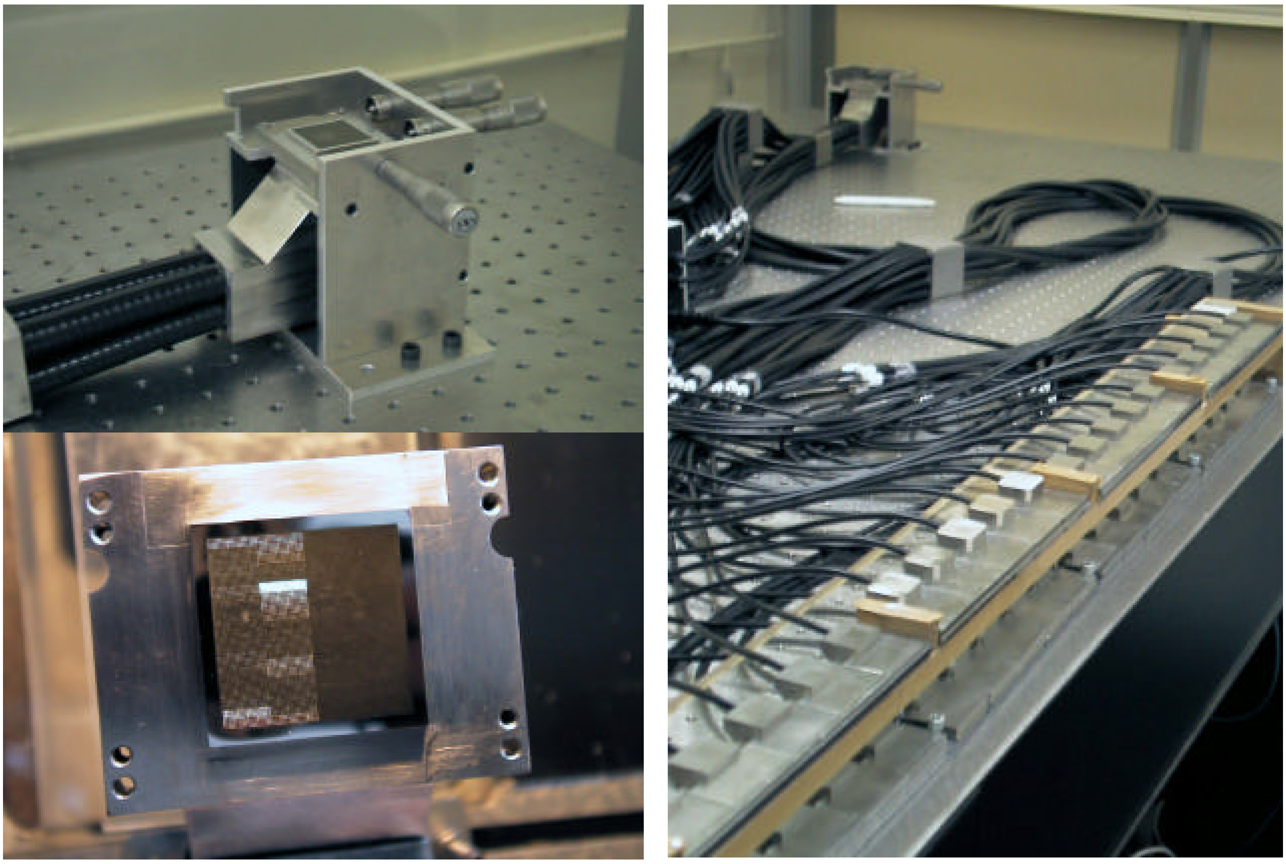


Figure 15: The VIMOS Integral Field Unit. The fiber bundle head (top left) includes an array of 6400 micro-lenses made of two crossed arrays of cylindrical silica lenses, feeding 6400 fibers (bottom left). At the fiber output, 80 lines of 80 fibers are coupled to linear micro-lens arrays before feeding the VIMOS spectrograph (right).

4. NIRMOS: THE NEAR INFRARED MULTI-OBJECT SPECTROGRAPH

4.1 General layout

NIRMOS has been designed to be as similar to VIMOS as possible in order to minimize development cost. The main differences from VIMOS are related to the "cold optical box" COB, and the detector cryostat. The COB includes collimator, grisms, camera and the interface to the detector cryostat. It is cooled to -50C so as to limit the thermal background coming from the instrument to allow spectroscopy at R~2500 to remain limited by sky background and detector noise, rather than by the instrument thermal background, up to 1.65 microns. This compromise allows to accommodate a wide field, 4×6×8 arcmin² (larger in imaging), and high multiplex gain from 0.9 to 1.65 microns at the limiting performances allowed by the sky background, while performances are degraded by ~0.5 magnitudes at 1.8 microns because of the increased thermal background. The alternative solution was to cool the full instrument, including the masks in the focal plane. The technical limitations imposed by this more complex solution would have forced to limit the field to only 8×8 arcmin² or so, therefore ~4 times less efficient from 0.9 to 1.65 microns, with strong operational constraints to load/uload the masks. Full spectrograph cooling is more appropriate for a spectrograph working up to the full K band.

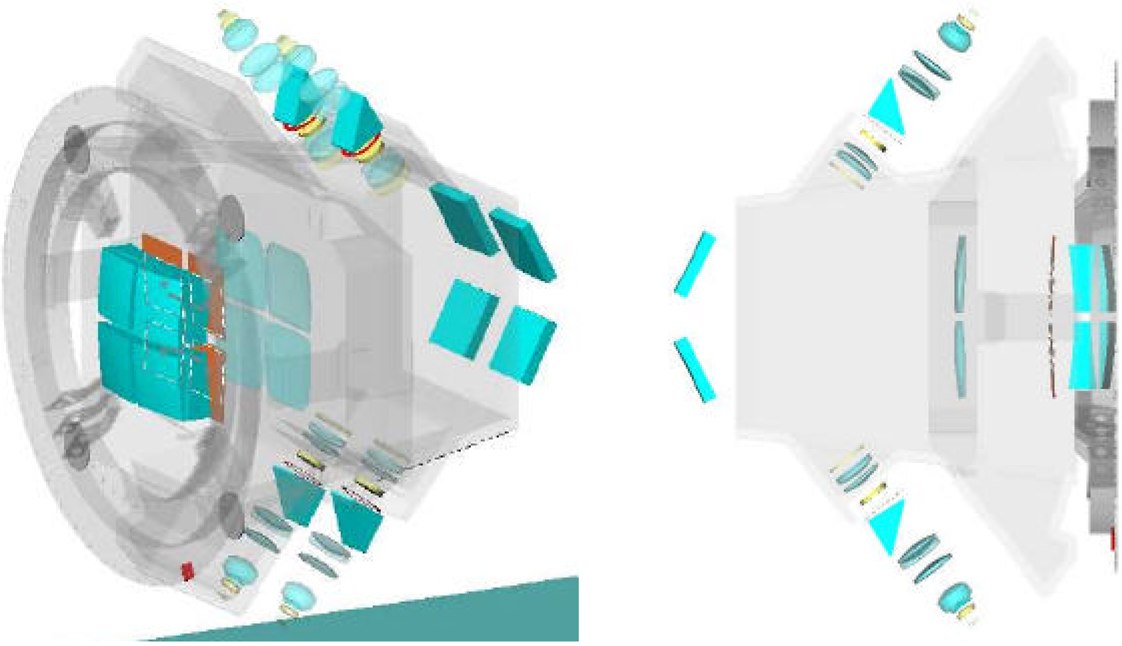


Figure 16: NIRMOS general layout (left), and optical layout of 2 of 4 channels (right)

4.2 Optical design

The general layout is presented in Figure 16. The details of the camera design are presented in Figure 17.

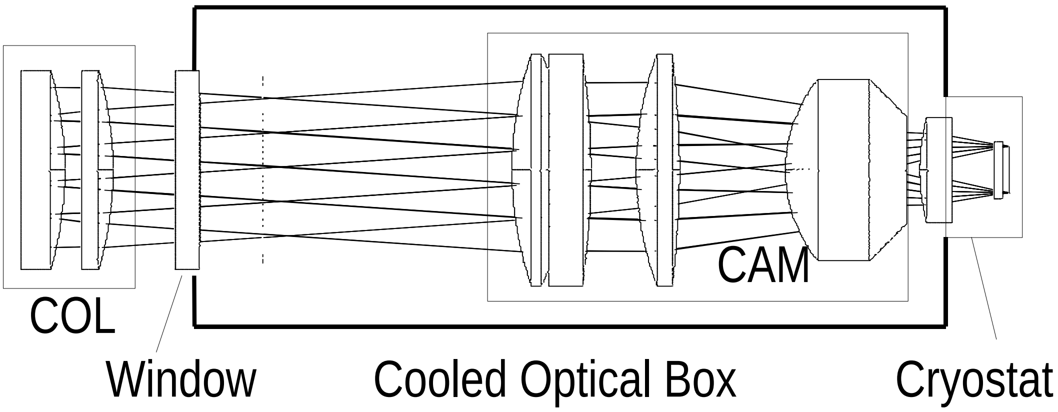


Figure 17: View of the optical design showing the last element of the collimator, and the camera

4.3 Cooled Optical Box

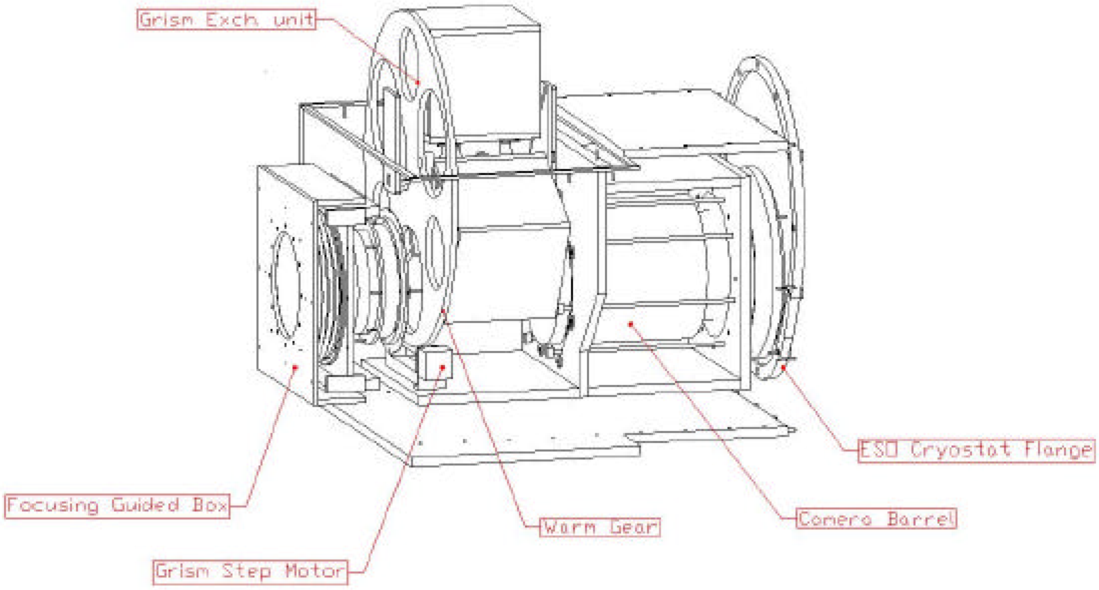
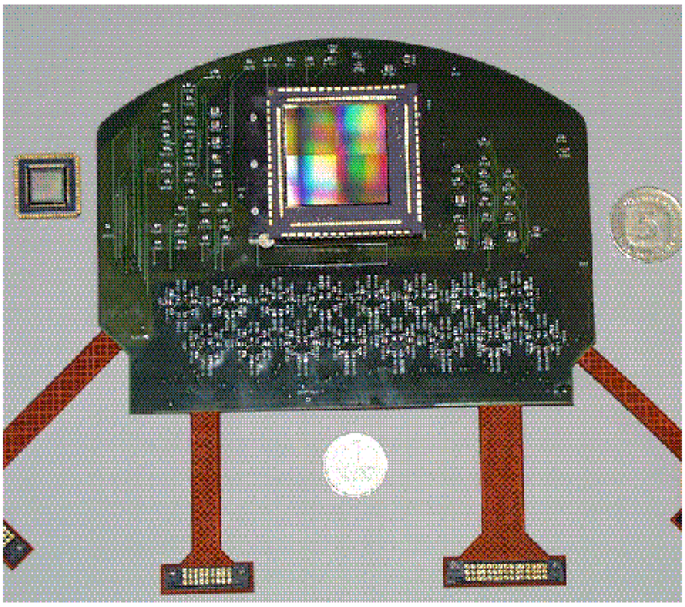


Figure 18: NIRMOS cooled optical box: this unit is cooled to -50C

4.4 NIRMOS detectors

The detectors procured by ESO are 4 large formet 2048×2048 pixels HgCdTe detector arrays with a cutoff wavelength of λc=1.9µm. Four detector cryostat each housing one detector and a cooled filter wheel will be manufactured by the ESO infrared detector team, as well as one data acquisition system to read all four arrays simultaneously. The detector procurement is on-going with Rockwell. Four science grade MBE arrays will be delivered early 2002. For the first months of operation, NIRMOS will use one 2048×2048 2.5 microns cut-off LPE array currently being manufactured.



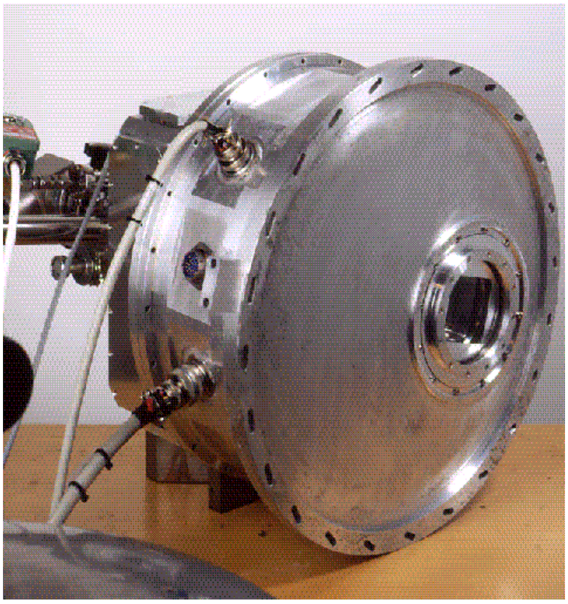


Figure 19: (left): the Rockwell 2048x2048 multiplexer on the NIRMOS detector board, on the lower part of the board, 32 cryogenic pre-amplifiers can be seen, a NICMOS-3 256x256 array is shown on the left for comparison. (right) the NIRMOS test cryostat

5. THE MASK MANUFACTURING UNIT

5.1 The mask manufacturing machine

The mask manufacturing machine is build around a LPKF – STENCILLASER 600 standard unit (from LPKF, Germany). It uses flashlamp pumped Nd:YAG (1064 nm), with 60W power 60W and a pulse rate 4000 Hz (Figure 20). The laser cuts through 0.2mm thin sheets of Invar material chosen so as to minimize thermal dilatation of the masks in the focal plane. Masks are handled by the masks handling system (Figure 20), storing masks in their respective loading cabinets, and using a bar-code reader to keep track of the mask manufacturing process. Off-line storage and monitoring of several hundred masks is provided.

Figure 20: Mask Manufacturing Machine (left,), and Mask Handling System (right)

5.2 Slit cutting performances

The optimum cutting speed is at around 6mm/sec. This allows to cut 800 slits in the 4 masks quadrants in less than 45 min, including overheads generated by the handling of 4 separate masks. The r.m.s. slit edge roughness is less than 1 microns, while the maximum peak-to-valley irregularities observed are less than 10 microns in any slit. Compared to the scale of 570 microns per arcsecond, the slits cut by this machine have excellent performances.

6. ACKNOWLEDGEMENTS

The VIRMOS development is done under contract with the European Southern Observatory. We acknowledge support from the CNRS of France, the CNR of Italy, the Observatoire Marseille-Provence and the region Provence-Alpes Côte d'Azur.

7. REFERENCES

1. Le Fèvre, O., Crampton, D., Felenbok, P., Monnet, G., A&A, 282, 325, 1994
2. Allington-Smith, J., et al., Proc. ESO conf.
3. Oke, J.B., et al., PASP, 107, 3750, 1995
4. Szeifert, T., et al., "Testing FORS - the first focal reducer for the ESO-VLT", SPIE 3355, pp 20-27, 1998
5. James et al., "DEIMOS: a wide field faint object spectrograph" SPIE Vol. 2871, pp 1107-1115, 1996
6. Davies, R., et al., "The Gemini multi-object spectrographs", SPIE 2871, pp1099-1106, 1996
7. Le Fèvre et al., "VIRMOS: visible and infra red multi-object spectrographs for the VLT", SPIE 3355, pp 8-19
8. Prieto, E., et al., "The VIMOS integral field spectroscopy unit", these proceedings