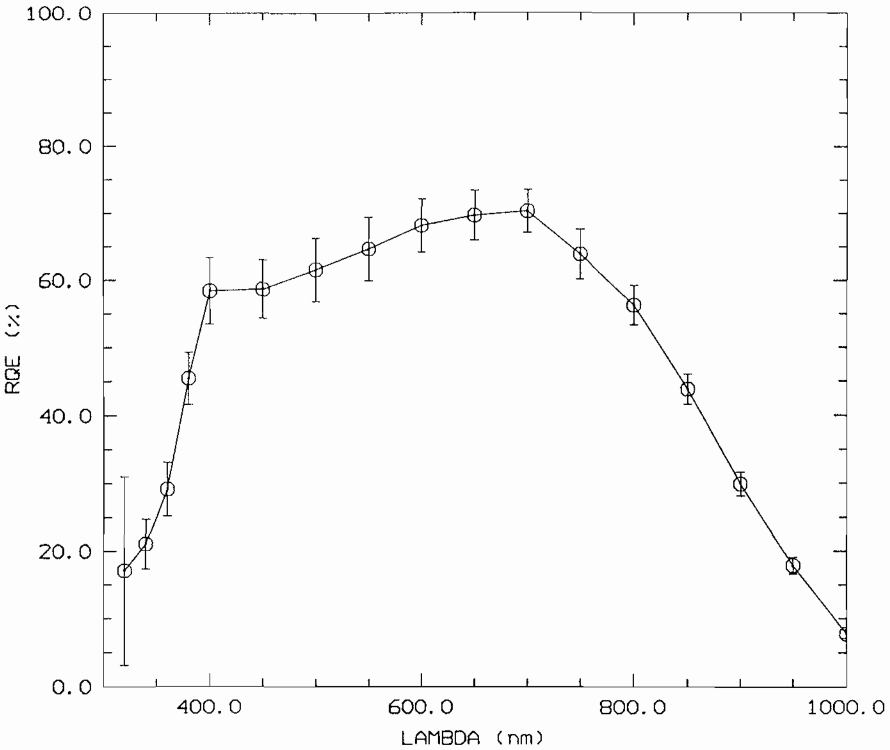

Figure 3: *Quantum efficiency curve of the thinned 2048^2 CCD (ESO #36) as measured in the ESO detector laboratory.*

This long reading time is due to the large number of pixels through a single output of the CCD but also to the limitation of the present ESO acquisition system based on the A900 computer. It is envisaged to replace it with a more efficient system based on VLT standards at the end of 1995. At present an option available to the user is the read-out through two outputs of similar characteristics (but not identical, thus requiring separate calibrations). The gain in slow mode is then 80 seconds. A quick-look mode (2 outputs, fast read-out, binning 2×2) requires about 1 minute.

Table 1: Main properties of the ESO CCD #36

Usable pixel number and size	2086×2046, 24 µm
QE	See Figure 3
Read-out noise (slow)	4.8 e/pixel
Read-out noise (fast)	8 e/pixel
Linearity	Better than 1 % from 30 to 200,000 e/pixel
Cosmetics	~10 partially hot columns (Amplifier D)
Dark current	≤5 e/pixel/hr at 151 K
Cosmic ray event rate	4 events/min/cm^2

An Updated EMMI Operating Manual

As of April 1st, 1994, the NTT has entered a new operation scheme which also foresees a major upgrading of the control hardware and software with the goal to fully exploit the unique capabilities of this telescope (see Baade et al. in *The Messenger,* 75, 1). As part of this effort, version 2 of the EMMI and SUSI Operating Manual is being prepared by E. Giraud and it will be released in June 1994. More detailed information on performance and data format of the instrument with the new camera and CCD will be included there.

Acknowledgements

The successful installation of the new camera and CCD is the result of the effort of several persons. H. Dekker planned and coordinated the activities in Garching and La Silla. O. Iwert, S. Deiries and R. Reiss put into operation and tuned the CCD in the laboratory. Again O. Iwert, R. Reiss together with P. Moore and P. Sinclaire installed the CCD and its controller at the telescope and optimized the performance there. T. Abbott has collected CCD test data at the telescope and verified the operating characteristics.

J.L. Lizon, H. Dekker and S. Moreau tested the optical camera in the laboratory. The first two later installed it at the telescope. They also conducted with Ph. Gitton a general check up of many EMMI functions. Astronomical test observations and/or their analysis were carried out by S. D'Odorico, J. Storm, and R. Mignani of the Dipartimento di Fisica of the University of Milano.

Test of an R4 Echelle Mosaic

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Why an R4 Echelle Grating?

The term "R4" describes one of the most important characteristics of an echelle grating, namely the tangent of the blaze angle. An R4 grating has a nominal blaze of 76 degrees, whereas the classical R2 has 63.5 degrees. Multiplied by the beam diameter, the tangent of the blaze angle yields the optical depth of the grating which determines the resolution that can be attained. The R4 echelle mosaic described here has a size of 450×130 mm, it is a down-scaled prototype version of the UVES[1] echelle which will have a size of 840×214 mm. To manufacture it, a novel technique has been developed in

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[1] UV-Visual Echelle Spectrograph. See *The Messenger* **70**, p. 13 for a full description of this dual-beam, cross-dispersed VLT instrument.

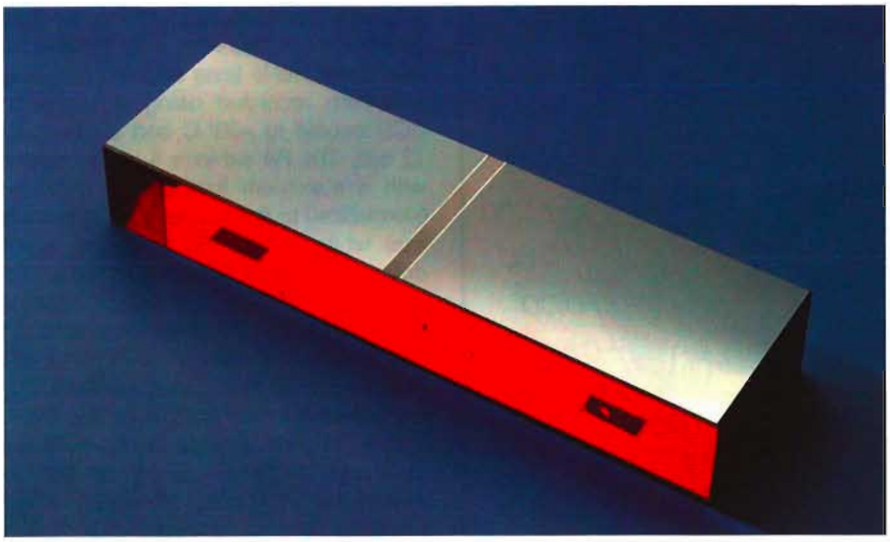

Figure 1: *Photograph of the R4 prototype. The dimensions are 450×130×70 mm; the dead space between the two segments is 14 mm wide.*

which two copies of the same master ruling are replicated on a common substrate, with a 14-mm gap between the segments. With its length of 450 mm, it is presently one of the largest monolithic gratings world-wide (Fig. 1).

Use of a steep R4 echelle has important consequences for spectrograph design. For the same spectral resolution, the beam diameter, collimator focal length and camera dimensions are reduced by a factor of two compared to an R2, which leads to a less costly, more compact instrument that is less affected by gravitational or thermal effects. This is why an R4 echelle was selected for UVES. On the other hand, while R2's can be mounted with a fairly large angle between incident and diffracted beams to separate the beams, R4's are much less forgiving and effects like spectral line curvature, spectral line tilt, grating anamorphosis (beam widening and variation of the line spread function along the order) and efficiency loss due to groove shadowing become more important and require a special spectrograph layout with the smallest possible angle between incident and diffracted beams.

The main purpose of ordering the R4 mosaic prototype was to compare the optical properties with those of R2 gratings, to test the manufacturing process, to identify possible effects of the segmentation of the grating surface and to test its suitability for astronomy in actual observations and data reduction. Of the available ESO spectrographs on La Silla, only EMMI works with a fairly small angle between beams (5.5 degrees; UVES has 1.8 degrees) so the prototype dimensions were chosen in such a way that it would be possible to be mounted on the red arm of EMMI with the possibility to reach R≈70.000 in a cross-dispersed format in the range 4100–7500 Å.

Design and Laboratory Characterization

There are several constraints for making large echelle gratings for astronomical instrumentation. According to information from grating manufacturers, present ruling engines cannot handle blanks larger than 300 mm×450 mm and still maintain the required groove positioning accuracy and surface flatness. Diamond wear limits the total length of the grooves that can be ruled. Funding the manufacture of a larger ruling engine was anyway considered not feasible at ESO.

In order to overcome these problems, one basically has the options (i) to build a mosaic from smaller identical gratings, all individually mounted and separately aligned (Keck HIRES spectrograph), (ii) to introduce active control by sensors, actuators and computers of individual gratings in such a mosaic (studied for the high-resolution spectrograph for the JNLT) or (iii) to build a mosaic out of smaller gratings replicated onto a single, larger piece of glass.

The technique used here is to assemble and precisely align a mosaic of submaster gratings and to replicate this mosaic in one single step onto a larger, single piece of glass. Main advantages of this approach are that it results in a maintenance-free, simple, robust and compact grating with constant performance. A first description of the concept was presented two years ago[2]. The R4 prototype realized according to this technique was delivered to ESO in November 1992 and was tested in the ESO optical laboratory in the course of 1993.

Blaze angle, efficiency, diamond wear and ghosts were tested on the smaller replica of MR 103-3 which for these aspects is considered representative. The absolute efficiency was measured at the blaze centre with ESO's TNO universal spectrophotometer in off-plane mounting with 5 degrees between inci-

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[2] H. Dekker and J. Hoose, 1992, ESO Workshop on High Resolution Spectroscopy, ed. M.-H. Ulrich.

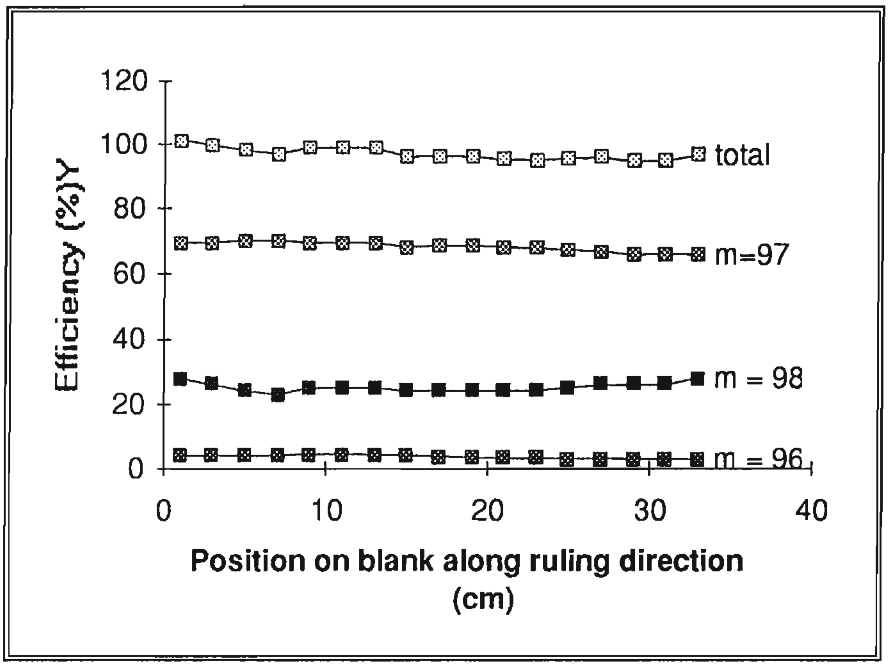

Figure 2: *Diffraction efficiency as a function of laser beam position on the test grating in the main and neighbouring orders at the He-Ne wavelength 6328 Å.*

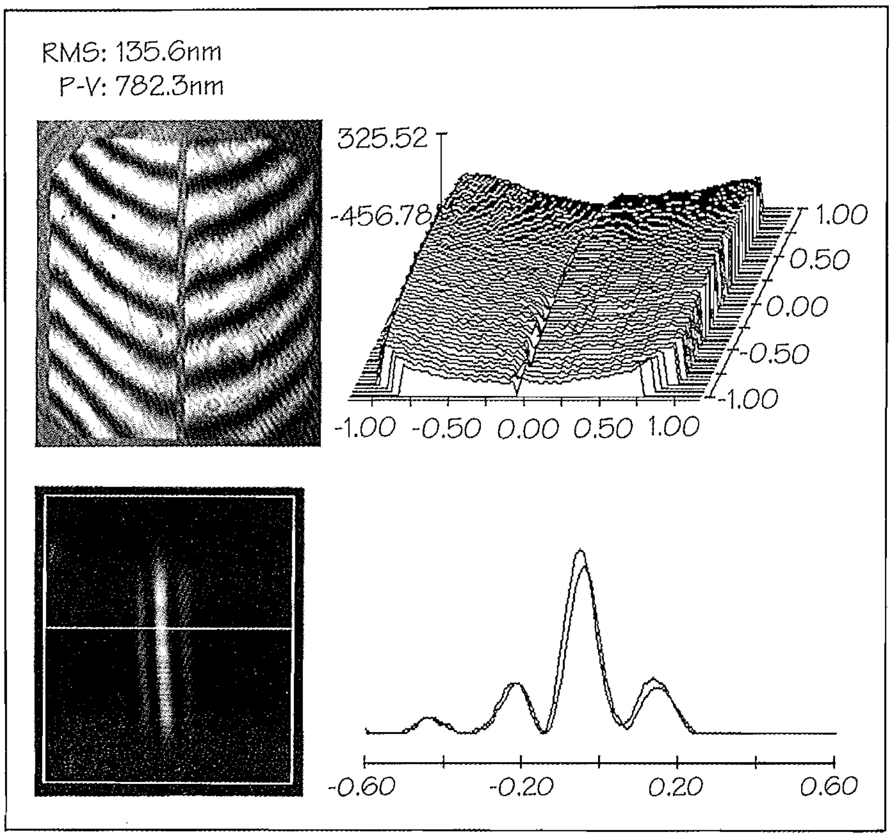

Figure 3: *Top left: interferogram of the mosaic in order 97. – Top right: computer representation of the wavefront with tilt and focus removed. – Bottom left: spectrum of He-Ne laser taken with a 1.3-m laboratory collimator/camera. The astigmatism is evident. – Bottom right: horizontal trace through the spectrum. The mode spacing of the laser is 640 MHz or 8.5 mÅ.*

dent and diffracted beams. The results and previous ESO measurements of R2 gratings are compared in Table 1 which shows that the efficiency of this R4 is almost as good as the 79 g/mm R2, which is one of the most efficient echelles.

The variation of diffraction efficiency at 632.8 nm in the main order (m = 97) and in adjacent orders was measured as a function of beam position on the surface; see Figure 2. This type of measurement is sensitive to variations in the groove shape and groove angle along the ruled area as might be caused by diamond wear, but there is very little sign of this. The diffraction efficiency in order 97 varies only slightly from 69 % at the start of the ruling to 68 % and 66 % in the centre and at the end, respectively while comparison of the curves for orders 96 and 98 shows no sign of changing groove angle.

Tests of stray light and ghosts on a smaller replica of MR 103-3 with size 165 × 320 mm were carried out in the DAEC department of the Observatory of Meudon by J. Baudrand and P. Czarny using the Musicos fiber spectrograph[3] which was at that time undergoing laboratory tests. Since stray light is difficult to measure quantitatively as the level depends as much on the spectrograph as on the grating itself, the R4 grating was compared with its "sister" R2 grating MR 35-13-*-411 (see Table 1), the standard grating for this spectrograph. The fiber was illuminated with a red HeNe laser and the resulting spectrum recorded using a Thomson CCD cooled to –30° C and digitized to 12 bits. The R4 exhibits 4 ruling ghosts with a maximum intensity of 0.029 % (normalized to the intensity of the parent line) while for the R2 7 ghosts were detected in the CCD field of view; the brightest one was 0.037 %. Interorder stray light in this prism-cross dispersed spectrograph, measured with a flatfield lamp, was 10 % of the neighbouring continuum for the R2, 3 % on the R4.

Spectral and spatial resolution were measured on the R4 mosaic prototype itself in the ESO optical laboratory with a diffraction-limited interferometric optical set-up and a red He-Ne laser. Figure 3 illustrates the resolution performance. The main defect is the astigmatism which is already present in the master. In the mosaicking process, the local surface slope of the submasters at the intersection was aligned in order to generate a more or less contiguous wavefront, save for a phase jump, with a P-V astigmatic deformation of 1.3 waves.

The mode structure of the HeNe laser is easily resolved, indicating a spectral resolution that is well in excess of 760,000. Due to the astigmatism, the spatial resolution is not as good as could be desired; the height of the PSF in the slit direction is ~100 μm, which corresponds to 0.55 arcsec (2 pixels with TEK CCD and F/5.3 camera) on the sky with EMMI.

The optical characteristics of the R4 mosaic prototype are summarized in Table 2 where its performance can be

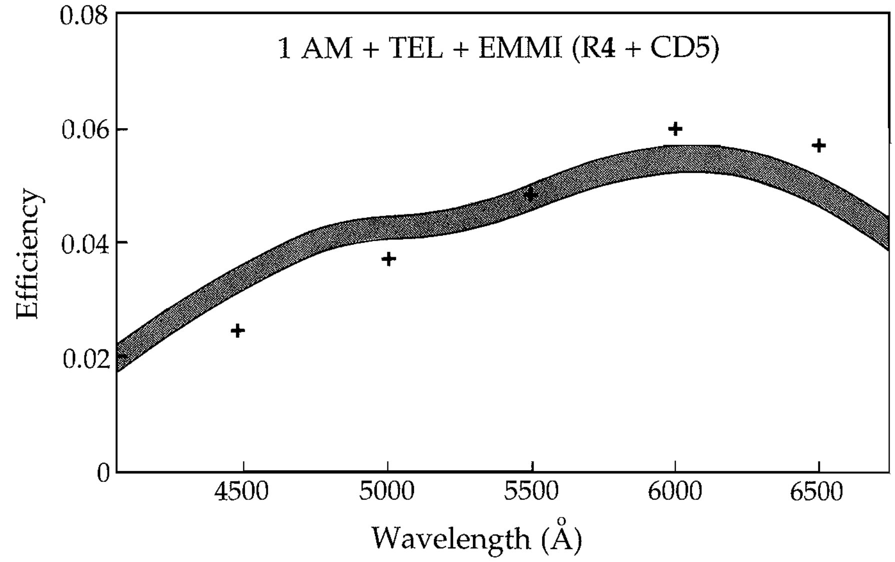

Figure 4: *Global efficiency curve for atmosphere + telescope + EMMI with the R4 echelle grating and CD5. A thinned 2048^{2}CCD from SITe was mounted as a detector. The width of the curve represents the difference between the observations of two different stars on two different nights. Crosses are average values for the same combination with the standard R2 grating (ESO #10 in the EMMI grating list).*

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[3] J. Baudrand and T. Böhm, 1992, *A&A* **259**, 711.

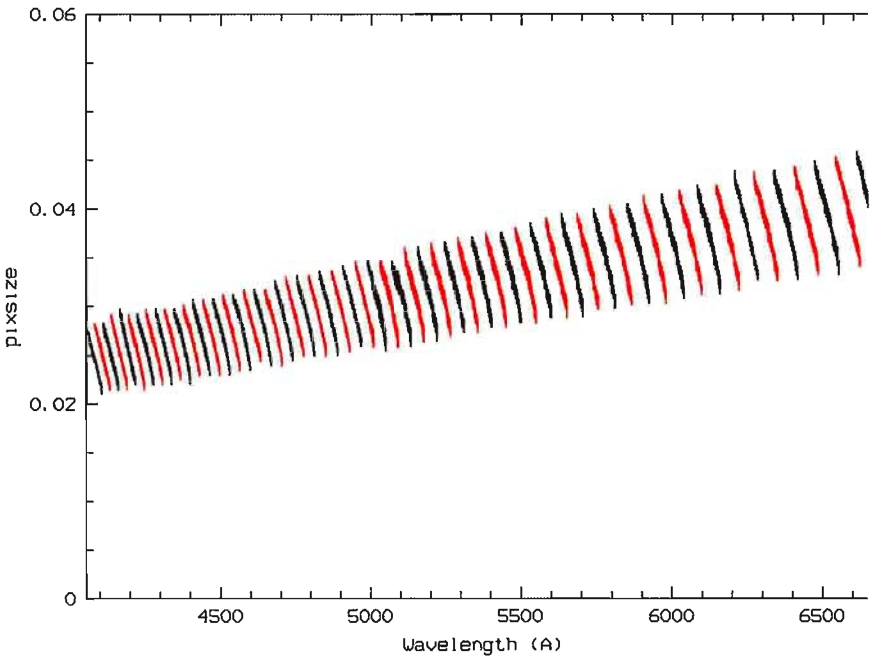

Figure 5: *Variation of the pixel size in Å along the orders of an echelle spectrum with the R4 grating and CD5.*

directly compared with the specifications of the UVES echelles that were agreed with Milton Roy and are now on order. The first delivery is expected by mid-1995.

Astronomical Tests on the EMMI Spectrograph

The EMMI spectrograph/imager at the NTT includes in its red arm an echelle mode which uses an R2 echelle grating and has a choice of four grisms as cross disperser[4]. For echelle observations, the standard grating unit is replaced by the unit which mounts the R2. A new mechanical housing was designed and built for the R4 prototype and installed on the spectrograph for two nights in February 1994. Table 3 summarizes the main characteristics of this grating on EMMI. The configuration which was mostly used during the test was based on the use of grism #5 as CD.

The two nights of observations were mainly dedicated to operational tests. Due to a problem with the slit width calibration of the EMMI slit unit that was discovered following the analysis of the data after the observations, the spectra were obtained with a mimimum slit width of 1.4 arcsec which resulted in a resolution of 45,000. The maximum resolving power which would correspond to a 2-pixel sampling of the slit on the detector, that is ≈70,000, has to be confirmed by new observations.

Figure 4 shows the global efficiency of the atmosphere (at air mass = 1) + telescope + instrument with the R4 grating and compares it with the values determined during the same run for the R2 grating (EMMI #10). The data are based on observations of two standard stars on two different nights. They show that R4 is generally as efficient as the R2 grating at most wavelengths and it surpasses it in the blue where the silver-coated R2 has lost some efficiency after 5 years.

The intensity of the interorder scattered light has also been measured from the standard star spectra. With or-

TABLE 1. *Absolute efficiency in % at blaze as a function of wavelength of some echelles*

	400 nm	500 nm	600 nm	700 nm
MR 103-3 (R4, 31.6 g/mm)	63	67	69	68
MR 35-13-*-411 (R2, 31.6 g/mm)	57	60	61	61
MR 35-13-*-401 (R2, 79 g/mm)	–	72	71	71

TABLE 2. *Main parameters of the prototype mosaic and of the UVES echelles*

	R4 mosaic prototype (results)	UVES echelles (specifications)
Dimensions	450×130×70 mm	840×214×125 mm
Number of segments	2	2
Ruling	existing ruling (Milton Roy 103-3) area: 165×320 mm blaze angle: ~75.5 degrees groove density: 31.6 g/mm	new rulings, nominal, nominal data: area: 214×420 mm blaze angle: 76 degrees groove density: 31.6 g/mm (red) 41.6 g/mm (blue)
Efficiency (surface average, including dead space between segments)	66 % at 550 nm	64 % at 550 nm
Spectral resolution	> 760,000	> 500,000
Spatial resolution	16 arcsec (0.55 arcsec on the sky with EMMI)	< 8 arcsec (0.2 arcsec on the sky with UVES)
Interorder stray light	<3 % of continuum (in Musicos spectrograph)	
Grating ghosts	<0.029 %	<0.015 %

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[4] D'Odorico, 1990, *The Messenger* **61**, 51.

der separations from 6.5 to 13.5 arcsec, the interorder intensity is below 3 % of the continuum intensity. No grating or optical ghosts were detected above the 1 % level. A systematic search at fainter levels has not been made yet.

Figure 5 shows the variation of wavelength bin size in Å as a function of order and within a single order. The strong variation of the wavelength bin within the order is an effect of the steep blaze angle of the echelle and has to be taken into consideration in the data reduction.

Finally, Figure 6 shows as an example of astronomical observations an untreated 1-hour spectrum of the nucleus of the Seyfert galaxy NGC 3783 (m(v)≈14).

In conclusion, the test of the R4 mosaic grating prototype on EMMI has confirmed the good performance which was indicated by the laboratory results and provides support to the choice of this type of solution for the VLT UVES spectrograph. Concerning a possible regular use of this grating in EMMI for scientific programmes, additional measurements will be needed to confirm the predicted limiting resolution and to test any flexure of the grating unit as the instrument rotates at the Nasmyth adapter. If these are successful, the R4 on EMMI would provide a unique possibility for obtaining spectra over a wide wavelength range at a resolution up to 70,000 for objects as faint as 16.5. If the users will express a strong scientific interest in such a facility, ESO will consider offering it as a standard option of EMMI as of 1995.

Acknowledgements

The R4 echelle was produced by Milton Roy (Rochester, USA) by the team led by John Hoose. The housing for mounting it on EMMI was designed at ESO by G. Hess. Thanks for the successful run at the telescope are due to the technical team which carried out the upgrading of the red arm of EMMI (see the report in this issue of the *Messenger*) and to P. Molaro (Trieste Observatory) for assistance during the astronomical observations.

TABLE 3. *Performance data of the R4 echelle on EMMI*

Resolution	45,000 wih a 1.4 arcsec slit (measured) =70,000 with a 0.7 arcsec slit (to be verified, see text)	
Wavelength bin	30 mÅ at 5000 Å	
Spectral formats	Wavelength range	Order separation
Recommended grisms 3	4070–8370Å	>3.7 arcsec
5	4070–6640Å (gaps beyond 7450Å)	>6.3 arcsec
Global efficiency (at air mass=1)	1 photon/Å/sec at 5500 Å for a star of m(v)=16.6	

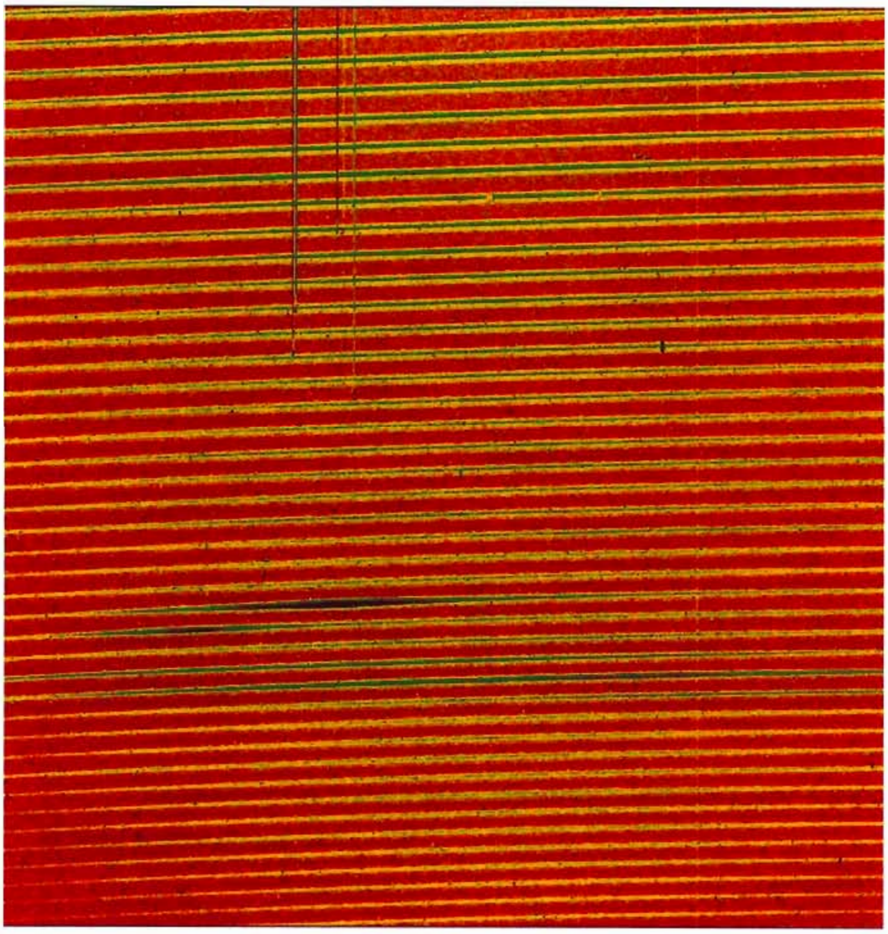

Figure 6: *Central 1400×1400 pixels of an untreated 1-hour exposure of the nucleus of the Seyfert galaxy NGC 3783 with EMMI and the R4 grating prototype. The broad $H\beta$ and the two [OIII] emission lines are visible in the lower half and interstellar NaI absorption lines in the upper part of the frame. At a potential resolution up to 70,000, this spectrum of a m(v)≈14 object has a S/N ratio≈40 in the continuum.*

News from La Silla

J. MELNICK, ESO-La Silla

3.6-m Pointing

An effort has been done to understand the behaviour of the pointing model of the 3.6-m telescope for different instruments. As a result, the methods for top-ring and top-end exchanges have been refined in order to avoid movement of the secondary mirror. Pointing is now stable. The software has been modified to permit fast models by adjusting only 8 parameters.

3.6-m Seeing

Progress has been achieved in understanding the bad seeing experienced at the telescope after the installation of the AIRCO cooling system. Measurements made by installing DIMM1 inside the