EMMI & SUSI

The ESO Multi-Mode Instrument and The Superb Seeing Imager

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ESO OPERATING MANUAL No.

Version No. 1

September 1992

Contents

List of Figures

List of Tables

Chapter 1

Introduction

This manual describes the operation of the ESO Multi-Mode Instrument (EMMI) at the New Technology Telescope (NTT) on La Silla. EMMI is a very flexible instrument which allows a wide range of observing modes, from wide-field imaging to high-dispersion echelle spectroscopy, including long-slit and multiple-object spectroscopy. This manual also includes SUSI (SUperb Seeing Imager) which, although mounted in the other Nasmyth focus of the NTT, complements the capabilities of, and can be used concurrently with, EMMI. A brief description of the active optics system of the NTT and its basic operational principles is also provided in this manual.

1.1 History

The idea to develop an efficient long-slit spectrograph to replace the standard B & C in use at the 3.6m dates back to the late 70s. With the approval of the New Technology Telescope Project, it was decided to build the new instrument for the new telescope. The driving concepts in the instrument definition were the high image quality foreseen for the NTT, the need to complement or improve 3.6m instrumentation, and the need to minimize instrument change-overs. The concept which was finally adopted in November 1985 is that of a dual-beam instrument, fully dioptric, and based on the white pupil principle. CCD detectors were foreseen for the two arms with the possibility to adapt to the geometric characteristics of future detectors by changing the cameras only. The main advantages of this type of design are the high efficiency in both channels and the easy conversion from wide field imaging to grism and grating spectroscopy. The instrument was installed at the Nasmyth focus B of the NTT in the spring of 1990, and commissioned in July and October of the same year.

After the first observations with the NTT, it became clear that the telescope and the atmosphere at La Silla could provide stellar images with diameters as good as 0.3″. Images of this quality could not be sampled adequately with EMMI, whose scale had also to be adapted to the spectroscopic modes of observation. Thus, SUSI was designed and built for the other Nasmyth (A) arm of the NTT.

Chapter 2

System Overview

2.1 Optical design

A detailed description of the optical design of EMMI can be found in Dekker et al. (1986). Figure 2.1 shows the optical layout and identifies the main components of the instrument. The blue channel is coated for high efficiency in the region 300 to 500 nm, the red for 400 to 1000 nm. There are various modes of operation in each channel, and detailed efficiency curves for the various modes are given in Appendix B.

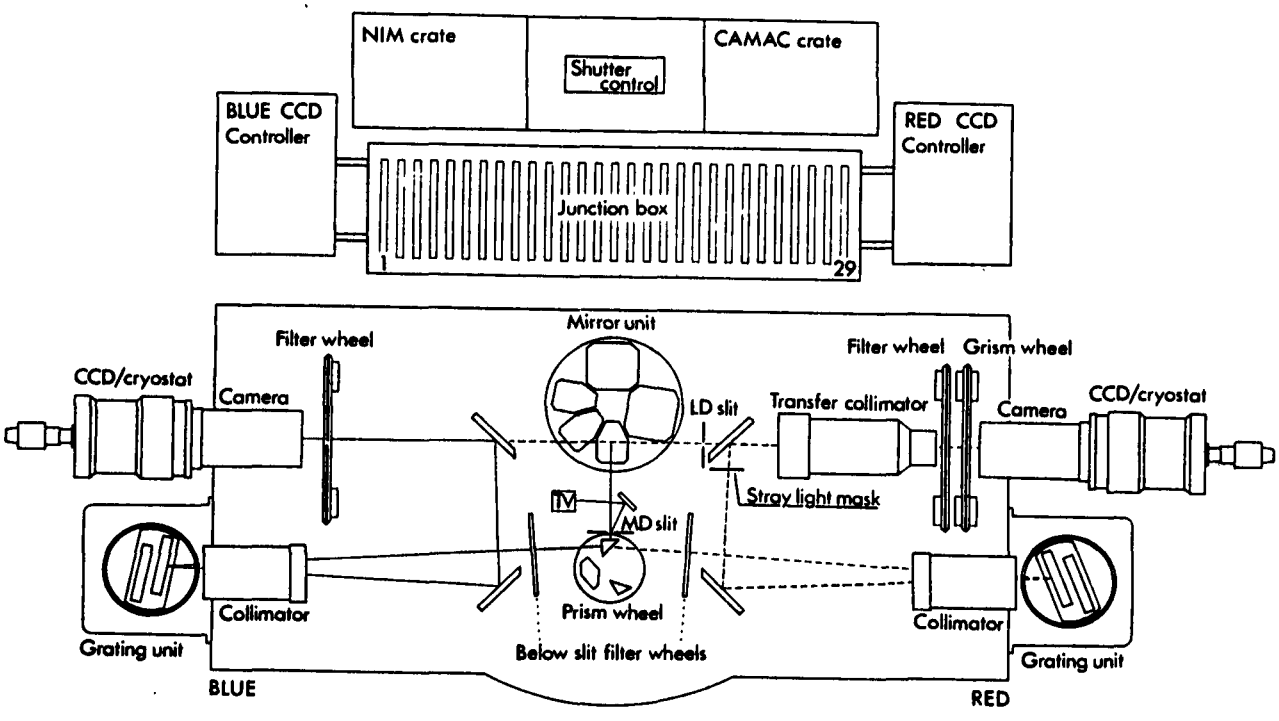

Figure 2.1: *Schematic layout of EMMI showing locations of the main components.*

2.2 Observing modes

EMMI offers 5 observing modes; two in each arm plus a combined mode that allows both arms to be used simultaneously for grating spectroscopy. The 5 observing modes are summarized in Table 2.1

Table 2.1: *Types of observations possible in the various modes of EMMI*

Mode	Observation type
RILD	Wide-field imaging Low dispersion long-slit (grism) spectroscopy Low dispersion slitless spectroscopy Multiple-object spectroscopy
BIMG	Wide-field imaging
REMD	Medium dispersion long-slit (grating) spectroscopy Cross-dispersed echelle spectroscopy
BLMD	Medium dispersion long-slit (grating) spectroscopy
DIMD	Simultaneous observing in REMD and BLMD

The light paths in the various modes are illustrated in Fig. 2.2. In the Red Imaging and Low Dispersion mode (RILD) the instrument works as a normal focal reducer with the possibility of doing imaging and low dispersion (grism) spectroscopy, and is thus very similar to the EFOSC instruments at the 3.6m and 2.2m telescopes on La Silla. Multiple Object Spectroscopy (MOS) is also possible in this mode. Unlike EFOSC, however, in EMMI the punching machine is incorporated in the instrument. Thus, slitlets are punched inside of EMMI and are automatically positioned in the focal plane of the instrument for MOS spectroscopy. A special program running in MIDAS allows the user to define slit positions and lenghts.

To switch to Red Medium Dispersion grating spectroscopy (REMD), the light coming from the telescope is first diverted downwards, instead of sideways, to the intermediate dispersion slit unit. A small prism below the slit sends the beam to the collimator and grating. After a second pass through the collimator, an intermediate spectrum is formed which is re-imaged by the focal reducer on the CCD (the upper folding mirror is inserted into the beam in this case). In the case of echelle spectroscopy, one of the grisms is used as a cross-disperser.

The same optical principle is followed in the blue arm except that grism and echelle spectroscopy are not possible. Here EMMI offers only the possibility of direct imaging (BIMG) and medium dispersion long-slit spectroscopy (BLMD).

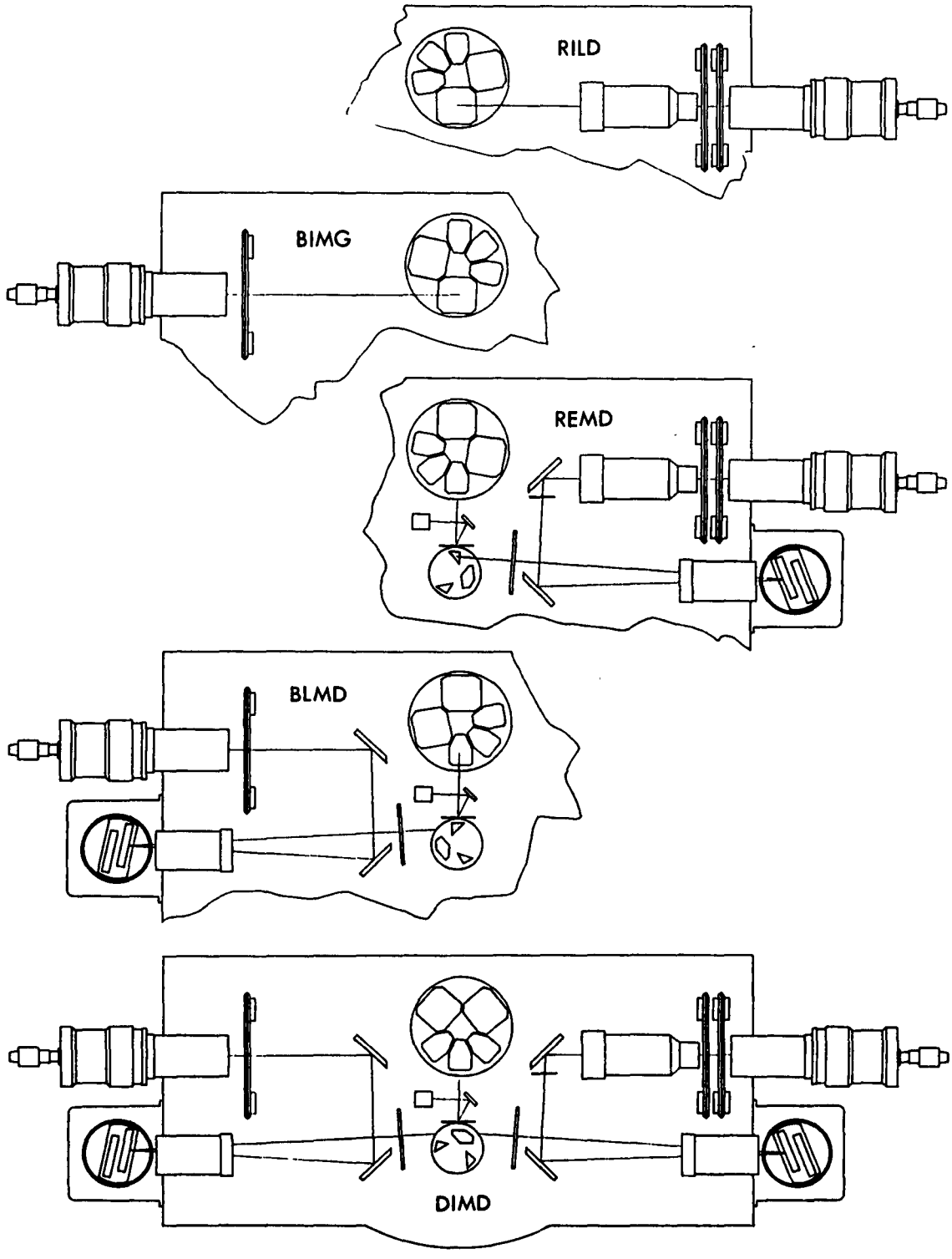

Figure 2.2: *Lightpaths in the five observing modes of EMMI and the corresponding positions of mirror unit, prism wheel, and folding mirrors.*

In the combined mode (DIMD), a dichroic beam-splitter below the intermediate dispersion slit sends the light to the red and blue arms simultaneously.

EMMI has an Atmospheric Dispersion Corrector unit (ADC) that is located in front of the mode selector unit and can thus be used in all modes. Wideband (low dispersion grating, grism, echelle and DIMD) spectroscopy will benefit most from this facility. The ADC consists of 4 discrete prisms with dispersive powers of $1'', 2'', 3''$, and $4''$ (from 320 to 1000 nm) that are mounted on a 5-position wheel. The first position is free. Each prism corresponding to a particular range of zenith distances, as shown in Table 2.2, can be rotated about its center so its dispersion compensates for atmospheric dispersion (see also reference [2]). The prisms provide an unvignetted field of 6 arcmin in diameter. With the free position selected, the field is 10×10 arcmin.

Table 2.2: *Zenith distance range of ADC prisms*

Prism #	**Zenith dist.** (deg)	**Dispersion** (arcsec)
free	0 – 11	–
1	11 – 29	1
2	29 – 43	2
3	43 – 52	3
4	52 – 60	4

Alhough all parts of the ADC unit are physically present on EMMI, the control software for this unit is not yet completed so the ADC unit is normally put in position "free" and disabled by the Operations staff during the observations. If it is not disabled, you should select position `free`.

2.3 Instrument control

The NTT is controlled by two HP1000/A990 computers, one for the telescope (called NTT) and one for the instruments (called NTI). The control software of EMMI is organized in such a way that EMMI is presented as 5 sub-instruments called RILD, REMD, BIMG, BLMD, and DIMD. Depending on the type of observations, the user selects one of these modes and the control software automatically moves the functions to be set for this mode. This leaves only the parameters of the particular type of observation to be defined. For instance, when setting up an exposure in RILD, the mirror unit and the upper red folding mirror are automatically set, so of the 29 EMMI functions, the observer must only specify the camera focus, the setting of the slit, filter, and grism wheels, and the CCD exposure parameters.

The user interface consists of a RAMTEK monitor where mouse driven menus and forms are displayed, and a normal CRT where messages from the system are given and typed commands may be entered. Parameters are entered by filling forms in the RAMTEK screen. IHAP and MIDAS are available on-line, and data storage is simultaneously possible in both systems.

2.4 Detectors

EMMI works with two CCD detectors, one at the red arm and one at blue arm. An additional intensified TV camera provides images of the central field of view of the telescope as reflected from the slit jaws in modes REMD, BLMD, and DIMD.

The image scale at the F/11 Nasmyth foci of the NTT is 5.36 arcsec/mm or 186 micron for 1 arcsec. This is also the scale of the direct imaging with SUSI. The unvignetted field offered by EMMI is 10×10 arcmin in RILD and 10 arcmin diameter in BIMG. With the F/2.5 red and F/4 blue cameras, this corresponds to a linear field of 25×25 mm and 37 mm $\emptyset$ at the CCD respectively. The THX1024 chip is not large enough to fully capture this field, while the FA 2048 is too large and must be windowed to 1700×1700 pixels. The actual field size and scale depends on the detector being used and is given in Table 2.3.

Table 2.3: *Image scale and field for EMMI and SUSI*

Mode	CCD type	Camera	Pixel size (μm/arcsec)	Field (arcmin)
EMMI RILD	THX 1024[a]	F/2.5	19/0.44	7.6×7.6
EMMI RILD	FA 2048[b]	F/2.5	15/0.35	10×10
EMMI RILD	TEK 2048[c]	F/5.3	24/0.26	8.9×8.9
EMMI BIMG	THX 1024	F/4	19/0.29	4.9×4.9
EMMI BIMG	TEK 1024[a]	F/4	24/0.37	6.2×6.2
SUSI	TEK 1024[a]		24/0.13	2.2×2.2

a. In use at present.
b. Tested on the instrument but presently not available.
c. Will become available during 1993 with the F/5.3 camera.

As these detectors may be changed on short notice, the details of their characteristics will not be included in this manual, but can be found in the ESO CCD manual, or invoking the MIDAS context `FILTERS` (X11 only) where the basic properties of all CCDs available on La Silla are given. Information about the CCDs currently mounted on EMMI may be obtained from the Astronomy Support Department on La Silla (EMAIL: `ASTRO@ls.eso.org`).

2.5 Instrument set-up

For each mode of EMMI there are a number of elements that can be installed in order to configure the instrument to your specifications. Thus, there is a range of filters, grisms, slits, deckers, and gratings which can be mounted on the instrument. Not all of these components can be mounted together and therefore you must specify the instrumental configuration required for your observations. This should be done one day before your observing run by filling out a special form available at the Astronomy Lounge on La Silla. The characteristics of the optical components of EMMI are given below.

2.5.1 Filters

EMMI has four filter wheels: the imaging blue and red filter wheels, and the blue and the red below slit wheels. Each of the two filter wheels used for imaging has 9 positions of which one is free.

All filters are permanently mounted in special cells which make replacement very easy. Although it is possible to use blue filters in the red and vice versa (one might want to do this in the overlap region, 400 to 500 nm), filters should be normally used in the wheel they are intended for. Red arm filters are mounted at 5° inclination to avoid reflections between the CCD and the filter. Blue arm filters, used in the converging beam in front of the blue camera, do not show this effect and are hence mounted with no inclination. The transmission curves of these filters are given in the ESO Image Quality Filters Catalogue (Gilliotte, 1992), and can also be obtained using the MIDAS context `FILTERS`.

EMMI red filters satisfy the requirement of image quality (as described in the ESO IQ filters catalogue) since they are operated in a parallel beam. Both red and blue filters must have a free diameter of 80 mm and an outside diameter of 85 mm. Adapter trays are available for other filters (e.g. EFOSC) but use of smaller filters will produce vignetted images only useful in the centre of the CCD. Table 2.4 gives a list of the standard EMMI filters available. Some filters have optical power and thus introduce a shift in the focus of the red arm of EMMI. These focus offsets, measured in the instrument, are given in the table whenever available. Offsets for other filters can be easily measured in RILD mode using the focus wedge with a pinhole mask in the aperture wheel, and the procedures `EMFOCUS` (IHAP) or `FOCUS` (MIDAS). In BIMG the focus offsets must be measured from stellar images.

2.5.2 Long–slit spectroscopy

For spectroscopic observations, EMMI has a grism wheel in the red arm and two grating units, one in each arm. Each grating housing mounts two gratings back to back; in this way the user has a choice of 4 gratings in a given observing night. Seven housings, four for the red arm and three for the blue, are presently available. The allocation of gratings to a given housing is permanent. No change of grating is possible during the night.

Figure 2.3 provides a global view of wavelength coverage and Rs products (nominal resolving power for a 1 arcsec slit) of the grisms and the gratings. The characteristics are

Table 2.4: *EMMI filters*

ESO	Filter	$\lambda_0/\Delta\lambda$ (Å)	Peak efficiency	Availability	Focus offsets
587	He I	4480/50	55	yes	-22
588	He II	4692/66	72	yes	-97
589	O III / 0	5014/56	64	yes	-2
590	O III / 3000	5057/64	52	yes	+7
591	O III / 6000	5112/61	69	yes	-5
592	O III / 9000	5160/63	68	yes	26
593	O III / 12000	5211/67	66	yes	0
594	O III / 15000	5260/66	65	yes	-3
595	N II / 0	6609/73	57	yes	0
596	H Alpha / 0	6570/72	52	yes	+19
597	H Alpha / 3000	6634/65	63	yes	34
598	H Alpha / 6000	6694/68	57	yes	20
599	H Alpha / 9000	6763/69	53	yes	30
600	H Alpha / 12000	6834/72	61	yes	35
601	H Alpha / 15000	6896/72	62	yes	-6
602	U	3540/540	67	yes	40
603	B	4230/940	65	yes	0
604	B (2)	4230/940	65	yes	
605	Bb	4150/1100	67	yes	-2
606	V	5420/1050	84	yes	+36
607	V (2)	5420/1050	84	no	
608	R	6450/1550	79	yes	0
609	R (2)	6450/1550	79	no	
610	I	8000/1580	94	yes	+6
611	Z	cut on 8420	85	yes	+4
643	BG38 2mm	4800/3200	97	yes	
644	GG375 3mm	cut on 3700	98	yes	
645	OG530 3mm	cut on 5300	98	yes	0
646	RG715 3mm	cut on 7220	98	yes	
647	Ne V	3427/82	42	yes	
648	O II / 0	3730/67	92	yes	
649	O II / 5000	3799/67	45	yes	
650	O II / 10000	3858/69	43	yes	
651	O II / 15000	3924/76	40	yes	
652	He II	4696/73	61	yes	
653	N II / 0	6590/31	57	yes	
654	H Alpha	6562/31	40	yes	
655	S II / 0	6732/72	60	yes	
656	9150	9137/194	92	yes	
657	S III / 0	9532/100	93	yes	
658	EUV (UG11/5)	3280/750	71	yes	
659	ND 0.3			yes	
660	ND 0.3			no	
661	ND 0.5			yes	
662	ND 0.5			no	
663	ND 1.0			yes	
664	ND 1.0			no	
665	ND 2.0			yes	
666	ND 2.0			no	
667	ND 3.0			yes	
668	ND 3.0			no	
669	ND 4.0			yes	
670	ND 4.0			no	

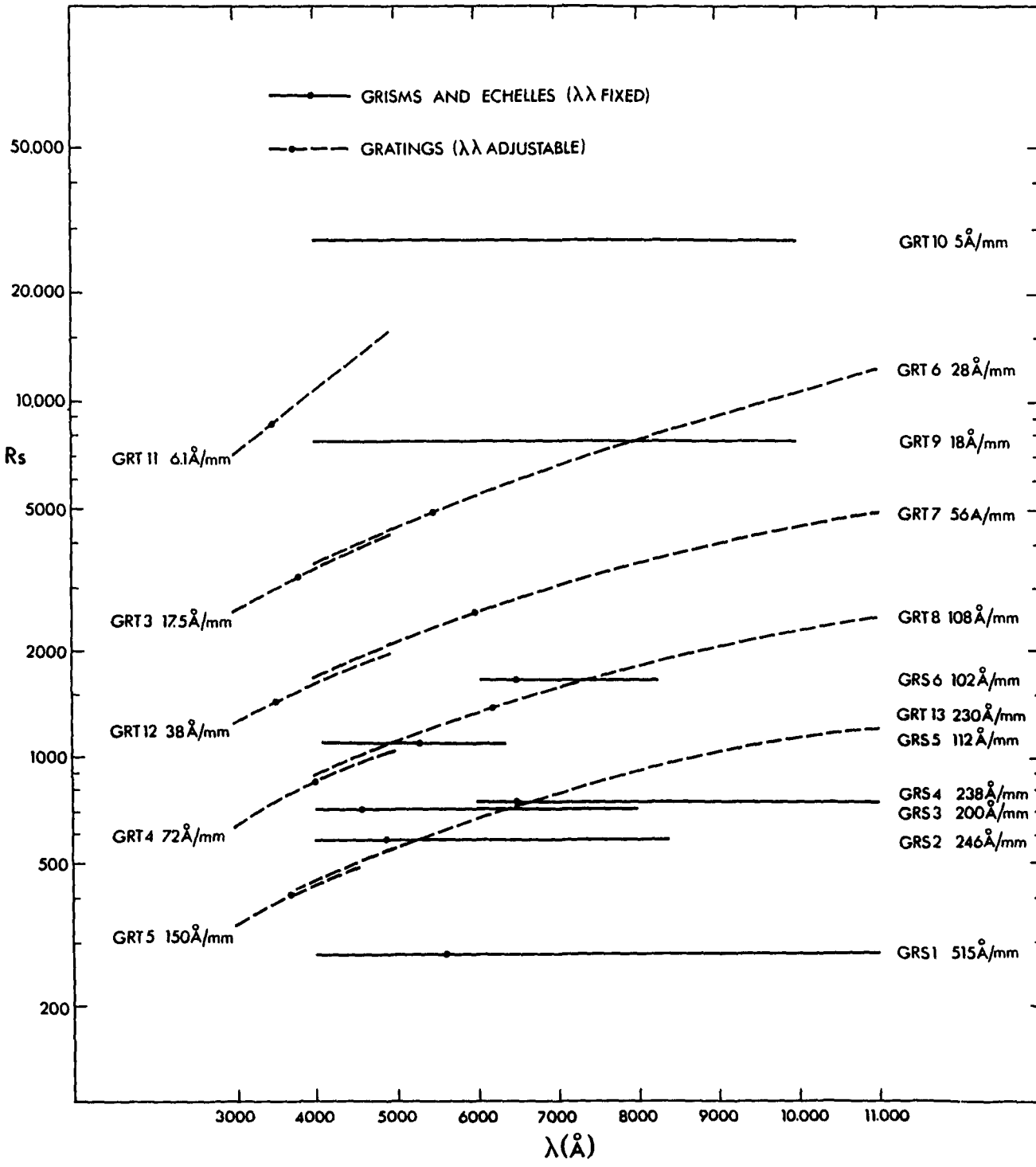

Figure 2.3: *Resolution and wavelength coverage of EMMI gratings and grisms*

listed in more detail in Tables 2.5 and 2.6. The efficiencies are given in Appendix B.

Low resolution spectroscopy is usually done in the red arm using grisms (RILD mode). With the present F/2.5 camera and the THX 1024 CCD the slit length is 7.5 arcmin. The widths of these slits (called *starplates* in the EMMI control software) are fixed, so in order to change slit widths a new starplate must be selected. The slit wheel has 5 positions, of which one is kept free for direct imaging. Thus, up to 4 long slits can be mounted at any given time. Available widths are 0.5″, 1.0″, 1.5″, 2.0″, 5.0″, and 10″.

The list of available grisms (for the red arm) is given in Table 2.5. These are permanently mounted on special bayonets which make replacement very easy. However, changing during the night is not recommended due to the need of aligning the dispersion with the CCD pixels. Notice, however, that the grism wheel of EMMI has 9 positions out of which 7 may be used for grisms (one is kept free for direct imaging, and one is used for the focus wedge), so the 6 grisms available at present may be mounted simultaneously. Examples of He-Ar spectra obtained through the EMMI grisms are presented in Appendix C.

Table 2.5: *EMMI grisms.*

Grism #	g/mm	Blz. ang (deg)	Blz. λ (Å)	Eff. (%) 1)	Disp. (Å/mm) 2)	Rs 3)	Wavelength range (Å) 4), 5)	Disp (Å/pix) 6)
1	150	8.6	5600	79	515	280	3900 – 10580	9.7
2	300	14.6	4900	78	246	580	3900 – 8245	4.6
3	360	15.0	4600	77	200	710	4045 – 7825	3.8
4	300	22.0	6500	72	238	740	5500 – 9895	4.6
5	600	34.0	5300	66	112	1100	4120 – 6330	2.2
6	600	54.0	6500	55	102	1670	6090 – 8050	2.0

Notes:

1) Efficiency at blaze.

2) With F/2.5 camera. Divide by 2.12 for F/5.3 camera.

3) Resolution with 1″ slit at 6000Å (at central λ for grisms 4, 5, and 6).

4) With F/2.5 camera and THX1024 CCD. Multiply by 1.2 for F/5.3 camera and TEK2048 CCD.

5) Second order overlap beyond 8000Å if not using an order sorting filter.

6) Divide by 1.7 for F/5.3 camera and TEK2048 CCD.

Low and intermediate dispersion spectroscopy in both arms (modes BLMD and REMD) is possible using gratings. The REMD mode also offers two echelle gratings for high dispersion work. The length of the slit in the intermediate dispersion modes is 6 arcmin in BLMD and REMD, but the useful length is determined by the detector/camera combination (see Table 2.3). The slit width in these modes can be continuously adjusted between 0 and 9 arcseconds. The slit length in the echelle mode must be limited using deckers to match the interorder separation.

The properties of the gratings available in the blue and red arms are listed in Table 2.6. Notice that, as is the case for some grisms, order separation filters are required for some of the gratings in mode REMD. These filters are mounted in the standard filter wheel and therefore do not affect the focus of the instrument (except for the offsets introduced by each filter as tabulated in Table 2.4).

Table 2.6: *EMMI gratings.*

Housing	Grating #	g/mm	Blaze angle (deg)	Blaze λ (Å)	Eff. (%) 1)	Disp. (Å/mm) 2)	Rs – 3)	Use in arm	Wavlth. range 4) (Å)	Remarks
A	1	—	—	—	—	—	—	blue	—	Mirror
	4	300	3.6	4000	72	72.0	840	blue	1700	
B	3	1200	13.9	3800	65	17.5	3400	blue	460	
	5	158	1.8	3700	72	150.0	400	blue	2500	
C	11	3000		3500	~50	6.1	11000	blue	120	Not yet avail.
	12	600		3500	~65	37.8	1700	blue	750	
D	6	1200	21.0	5500	72	28.0	5500	red	540	
	7	600	11.3	6000	68	56.0	2600	red	1080	5)
E	2	—	—	—	—	—	—	red	—	Mirror
	9	60	28.7	all	50–72	18.3	7700	red	grism	5)
F	10	31.6	63.5	all	52–65	5.0	28000	red	grism	5)
G	8	316	6.8	6200	70	108.6	1300	red	2100	5)
	13	150	2.2	5500	68	230.0	600	red	4500	

Notes:

1) Absolute efficiency at blaze.

2) With F/4 (blue) and F/2.5 (red) cameras. Divide by 2.1 for F/5.3 camera in the red.

3) Resolution with 1″ slit at 400 nm (blue) or 600 nm (red).

4) Wavelength range is recorded with the F/2.5 camera and THX1024 CCD (red), and F/4 camera and TEK1024 CCD (blue). Multiply by 1.2 for F/5.3 camera and TEK2048 CCD in the red. The wavelength range with the echelles is determined by the grism used as cross-disperser which also sets the order separation.

5) Second order overlap may occur in the red beyond 7800Å; use an order sorting filter.

2.5.3 The dichroic mode (DIMD)

A dichroic beamsplitter can be inserted in the beam in mode DIMD to allow simultaneous long-slit spectroscopy in the red and blue arms. This beam splitter is permanently mounted in the instrument and cannot be changed. The efficiency curve of the presently available unit is shown in Figure 2.4.

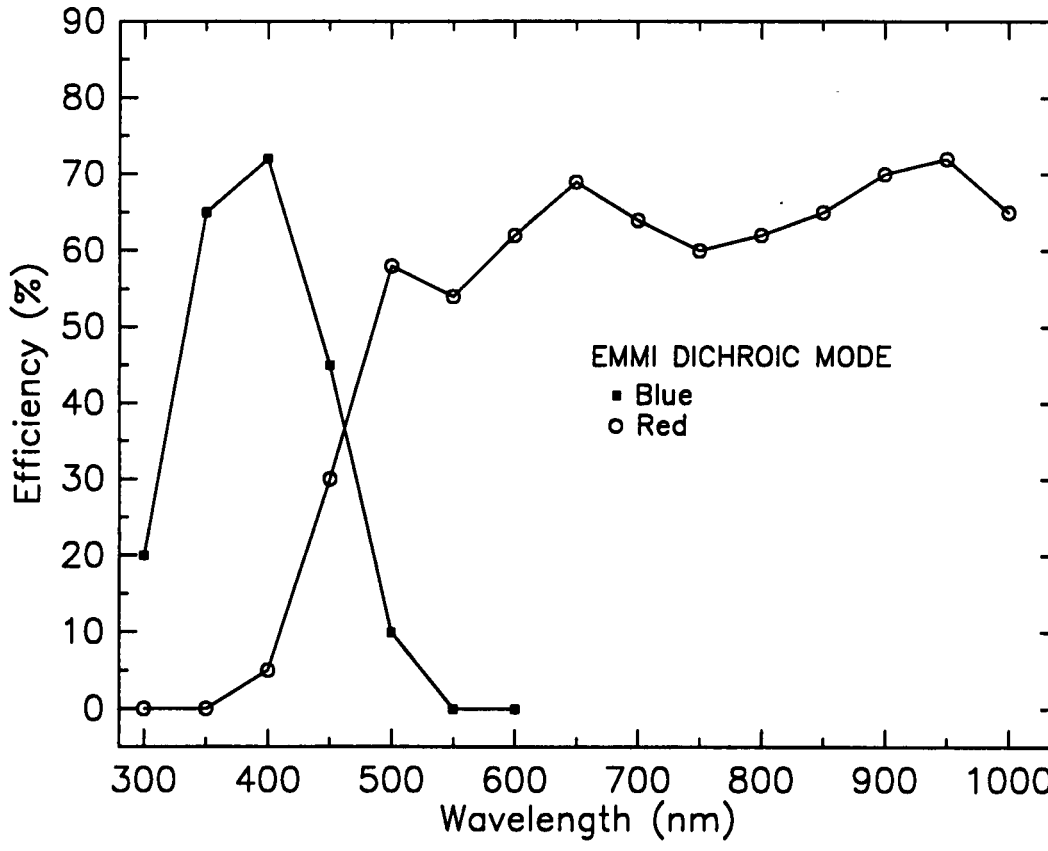

Figure 2.4: *Optical efficiency of EMMI in DIMD mode. The curve only includes the transmission of the EMMI optics and the dichroic beam splitter.*

2.5.4 Echelle spectroscopy

There are two echelle gratings (#9 and #10) which can be used in combination with a cross-dispersing grism to obtain data in an echelle format. The echelle grating #9 is mounted in a standard grating housing, but echelle grating #10 is mounted in a special unit. The installation requires using the crane in the instrument room and takes longer than a standard grating. For the echelle mode a decker has to be mounted to limit the length of the slit. There are three deckers available (5″, 10″, 15″) and the observers should indicate in the request form the one to have installed. The choice depends on the spectral region to be observed and on the grism used as cross-disperser. The selection of deckers is rather delicate because changing deckers during the night is not possible without the help of an optician and therefore is time consuming. Figure 2.5 gives the order separation in arcsec for grating #10 with 4 cross-disperser combinations and can be used to select the most suitable decker for your programme. This is not as critical with grating #9, where the orders are separated more widely (cf. Appendix D). The total efficiency of EMMI with echelle grating #10 measured observing standard stars through a wide slit on a photometric night is shown in Figure 2.6 for all cross-disperser combinations.

Table 2.7 summarizes the relevant properties of the echelle spectra obtained using different cross-dispersers. For representative orders, these tables list the spectral range, the resolution in the middle of the order, and the resolution in Å. Charts of the Th-Ar spectrum for each configuration are presented in Appendix D.

Table 2.7: *Echelle spectroscopy with EMMI.*

GRATING #9			
Grism CD	**Orders ***	**Wavel. range * (Å)**	**Mean resolving power**
3	22 – 36	4400 – 7610	6900
4	17 – 27	5960 – 9850	6500
GRATING #10			
Grism CD	**Orders ***	**Wavel. range * (Å)**	**Mean resolving power**
3	73 – 137	4200 – 7850	28000
4	58 – 99	5700 – 9900	28000
5	90 – 134	4200 – 6350	28000
6	71 – 91	6200 – 8100	28000

* Using the F/2.5 camera and a 1.2 arcsec slit with the THX1024 CCD.

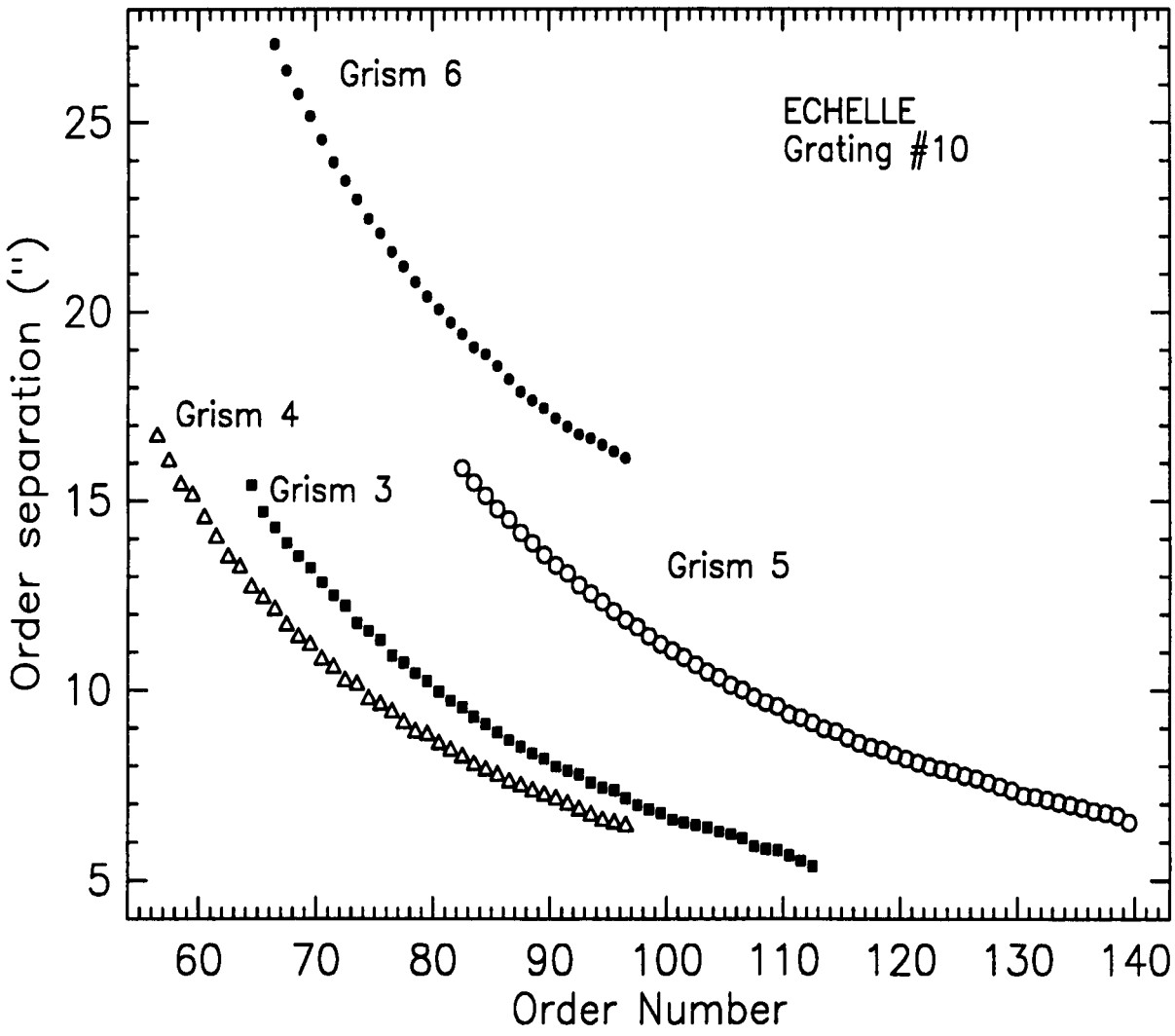

Figure 2.5: *Interorder separations for echelle grating #10 with different cross-dispersing grisms. Refer to Table 2.7 for the range of orders covered by the CCD currently mounted on the instrument.*

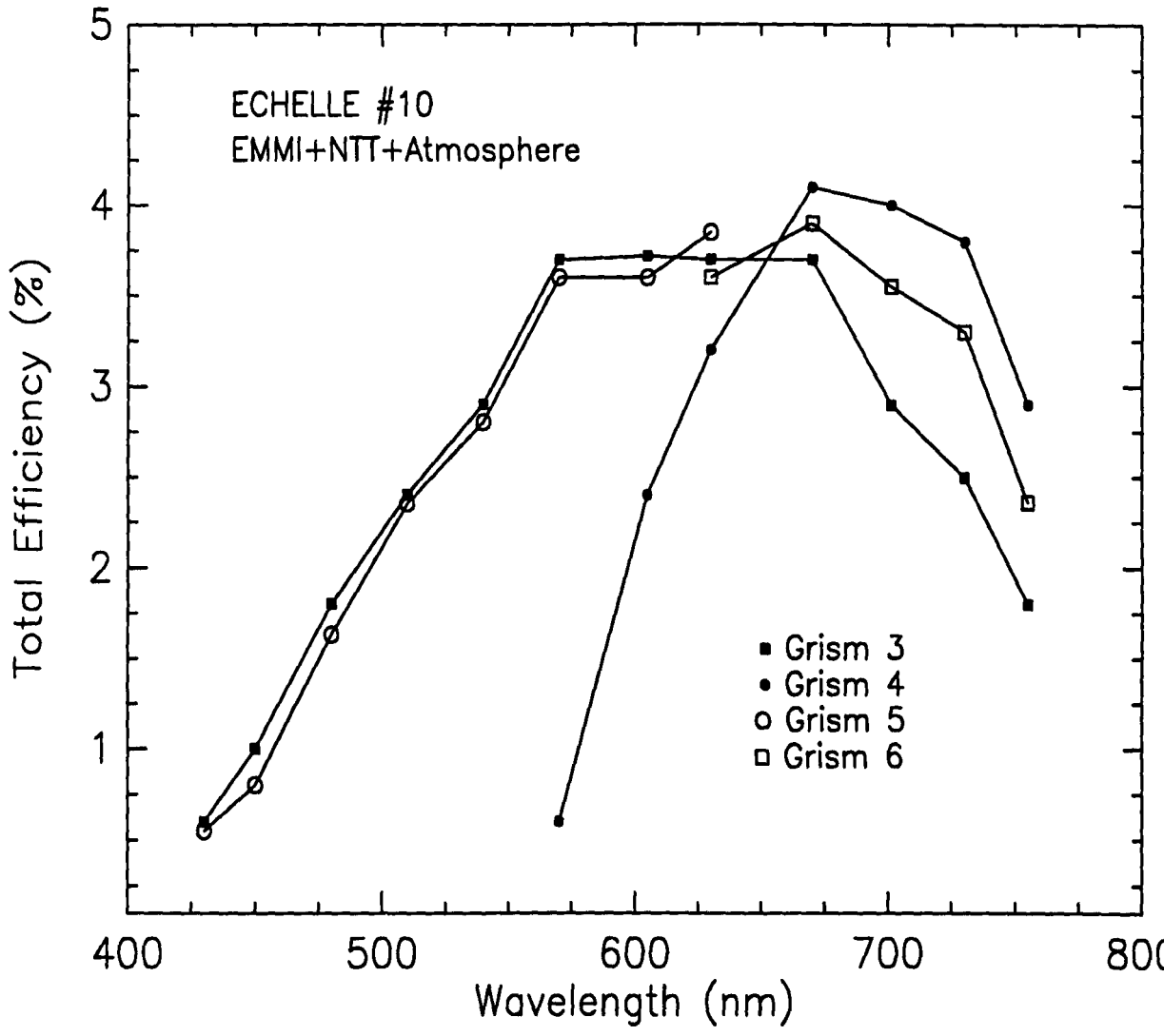

Figure 2.6: *Measured efficiency of EMMI with echelle grating #10.*

Chapter 3

Observing with EMMI

3.1 Getting started

The program that controls EMMI is called `OBST` (Observing Task). To run OBST, logon at the EMMI terminal (LU:53) with `RTE-A LOG ON : OBST` (no password is required; simply hit return when prompted), and follow the instructions appearing on the screen. During the initialization process, a special form called *Assembly* will appear on the OBST screen. The form requests the name of the observer and the programme identification, and asks you to set the flags which enable/disable communication with the relevant nodes of the NTT and CCD controllers. For normal operation during the night, all connections to these nodes (`EMMI, CCDR, CCDB, ADAPTB, TELNTT`) should be enabled (i.e. set to `TRUE`). If you have to start the system during the day, when the NTT is stopped, set the `TELNTT` flat to `FALSE`.

On the second terminal (LU:65), you may run IHAP by loging in with the username `EMMIHAP`. After login, press the first softkey in the terminal (`f1:` `IHAP EMMI`) to start IHAP. A number of softkeys will appear that allow you to manipulate IHAP in the standard way.

Once OBST is running, EMMI is operated using mouse driven menus on the RAMTEK User Interface (UIF). In order to operate the UIF, simply slide the mouse to the selected commands (that appear in bars on the right hand side of the RAMTEK monitor), and click at the desired command using the *middle* button of the mouse. EMMI is presented as 5 sub-instruments, each of which can be configured and operated independently. Thus, the observer is presented with 5 different menus, one for each mode of EMMI. Clicking these menus leads to more menus and forms to be filled that allow to setup the instrument and define exposures. Up to 6 instrument setups and 8 exposures may be predefined for each mode. Much of this can be done during daytime or during integrations so that mixing observing modes during the night is a relatively straightforward task.

On-line data reduction is possible both using IHAP and MIDAS. Both systems are fully implemented and the data are simultaneously transmitted to both systems. MIDAS runs on a SUN workstation with two monitors, the normal one used for standard MIDAS window, and one for image display. An automatic MIDAS procedure displays the new frames on this monitor. Data saving is possible both via IHAP and MIDAS, but only the IHAP data are archived.

3.2 Setting up EMMI

Once the instrument is configured according to the observer's request (see Section 2.5), a set-up form is produced. A printout of the form is delivered to the observer to be used as reference during the night and to verify the setup. The configuration of each mode will be displayed on the RAMTEK UIF whenever a setup is defined. An example of a typical EMMI configuration is reproduced in Figure 3.1. Besides showing the list of components mounted on the instrument, the form gives the temperature dependence of the instrument focus, the positions of the starplate slits for the RILD mode, and the filter offsets. The optical elements are mounted and aligned with the CCD rows by the Operations Group. Check that your selected grisms are labeled `ALIGNED` and call Operations should this not be the case. The slits should be aligned with the CCD columns and their positions measured and given in the form. Accurate slit positions are critical and are normally measured without filters. It is recommended to check these positions especially if you intend to point using filters. To do these measurements, simply take direct images of the slits using an internal lamp (He or Ar), and measure the position using `center/gauss` (MIDAS) or `SLCE` (IHAP) on 1-D cuts across the slits. The alignment can be checked by making several cuts along the slits.

During observations, the instrument configuration is done in two steps. First, the EMMI mode must be selected. This is done in the user interface by going first to `Top menu`. (This is the menu that appears after startup). After clicking `Top menu` the five EMMI modes appear on the UIF menu bar. Click the desired option. For example, for DIMD, click `DIMD-Dichr.Med.D.`.

After selecting the desired mode of operation, a number of options appear on the RAMTEK display. In order to setup the current mode, click the corresponding *setups* command. Thus, to setup RILD for example, click `RILD Setups`. A form will appear on the screen that allows you to predefine up to 6 instrumental configurations (for each mode). The list of optical components mounted for that mode will be displayed in the lower half of the RAMTEK screen. The forms are filled using the keyboard — *not the mouse* — cursor to step from one field to the next and typing the desired parameters. The *Tab* key may be used to skip a field. The optical components (filters, grisms, gratings, slits) may be defined either by their position in the corresponding wheels (e.g. 1, 5, 9, etc.), or by their names as they appear in the optical setup form (e.g. #1, 1.5″, ESO567, etc.). The fields marked `NOT ENAB.` in the setup screen should be ignored as the corresponding functions are not operational.

3.3 Defining and executing exposures

3.3.1 Exposure definition

To define exposures, simply click the *exposures* bar for a given mode. For example in BIMG mode, click the command `BIMG exposures`. A form will appear on the screen where the exposure parameters must be entered. Up to 8 different exposures may be defined (for each mode). The exposures form has two areas where system information is

```
=================================================================================
EMMI OPTICAL SETUP

TEL: NTT   OBS:_______________ SETUP BY:_______________ DATE:_________
=================================================================================
ADC prisms:  1.0''  , 2.0''  , 3.0''   , 4.0''   , free
=================================================================================
Blue imaging (BIMG)            |     Red Imaging and Low Dispersion (RILD)
                               |
Blue filter wheel (FILB)       | Red filter wheel (FILR)   Grism wheel (GRIS)
                               |                     focus
  name    identifier offset    |  name   identifier offs.   name  identifier
1 B       #603          -3     | 1 z      #611          3  1 #1    #1 ALIGNED
2 U       #602          40     | 2 H alph #654          5  2 #2    #2 ALIGNED
3 OII/5   #649           0     | 3 V      #606         32  3 #3    #3 ALIGNED
4 HE II   #588           0     | 4 R      #608          0  4 #4    #4 ALIGNED
5 He I    #587           0     | 5 I      #610          3  5 #5    #5
6 FOCW+B  #604 focwB     0     | 6 Bb     #605          2  6 #6    #6 ALIGNED
7 #1      HARTMANN       0     | 7 HALPHA #596         11  7 CD    FREE
8 #2      HARTMANN       0     | 8 BG 38  #543          0  8 FOCW     ALIGNED
9 FREE          FREE     0     | 9 FREE        FREE     0  9 FREE  FREE
                               |
                               | Starplate wheel (STAP)
                               |
                               |  name   identifier
                               | 1 FREE   FREE
                               | 2 5''    X=555.75
                               | 3 1.5''  X=552.8
                               | 4 2.0    X=555.7
                               | 5 MOS    RED000100
                               |
focus = 8458.0 + 3.0 * T       | focus =7910.0 + 3.0 * T   T in deg C
=================================================================================
Long slit unit (LOMS)

Decker mounter:  5''
=================================================================================
BLue Medium Dispersion (BLMD)| Red Medium Dispersion (REMD)
                               |
Blue grating unit (GRTB)       | Red grating unit (GRTR)
                               |
     name  identifier          |      name  identifier
     3     17.5A/mm            |    #  10    ECHELLE
     5     150 A/mm            |
                               |
Below slit filter wheel blue   | Below slit filter wheel red
(BSLB)                         | (BSLR)
                     focus     |                     focus
   name   identifier offset    |  name   identifier offset
 1 FREE                 0      | 1 FREE 0
 2 nd 1.0 ND 663        0      | 2 nd 0.5 ND 661 0
 3 nd 0.5 ND 662        0      | 3 nd 1.0 ND 664 0
                               |
focus = 7522.3 + 35.0 * T      | focus =7610.0 + 21.0 * T  T in deg C
=================================================================================
Dichroic Medium Dispersion (DIMD)
Blue focus offset =  25.0      | Red focus offset = -80.0
```

Figure 3.1: *Example of a typical setup form of EMMI. The form shows the optical elements that have been mounted on the instrument, and the temperature dependence of the instrument focus.*

given (located at the top and bottom of the form), and three areas used by the observer to define the exposure parameters as follows: the first area defines the exposures to be executed, sets flags to enable or disable automatic transfer of data to tape at the end of the exposures, and records the EMMI temperature for the automatic camera focus mode. Single exposures, or sequences of exposures may be defined. Thus, if you want to execute exposures 4 through 7 you must enter [4] – [7] at the top of this area. To execute only one exposure, its number must be repeated twice. In MODE DIMD, two consecutive exposures must be defined, one for the blue and one for the red CCDs. Unlike the other modes, however, in DIMD both exposures will be started simultaneously.

IHAP data are stored on standard 6250 BPI magnetic tapes using FITS format. There are two flags to set IHAP tape recording: the first flag specifies whether the data should be recorded on tape at the end of every exposure. If this should be the case, set to [T] (True). Else, set to [F] (False). For full frames tape recording is time consuming and some users prefer to do the tape saving manually. This is done using the command `WFITS` in IHAP. The second flag enables the automatic recording mode. In this mode the system keeps a log of the exposures not stored on tape, and allows tape transfer during exposures using the [`Start save on tape`] and [`Stop save on tape`] commands in the UIF. If the automatic temperature readout is enabled, the temperature of EMMI will be displayed after the tape control flags and the focus of EMMI will be automatically adjusted for temperature at the beginning of each exposure. If not enabled, a `NOT ENABL` message will appear next to the field.

The data are automatically stored on Exabyte tapes by MIDAS, provided a tape is loaded in the Exabyte drive, and the session `CCD/lasilla` is running on the MIDAS station.

The second user area of the exposure definition form consists of 8 lines with a series of fields where the actual exposure parameters must be entered. From left to right these parameters are:

Type: `dk` for dark; `sci` for scientific exposures; `foc` for telescope focus; `foi` for instrument focus; `cal` for exposures using the internal lamps, `cam` for multiple calibration exposures (i.e. expose more than one lamp on the same frame), and `ff` for flat field exposures. With the exception of `cam` these types are self-explanatory and straightforward to use. One `cam` exposure must be defined for each lamp. The parameters of all `cam` exposures must be identical with the exception of the exposure time and the lamp number (or name). Therefore if for example you want to make a He-Ar exposure you must define one exposure for the He lamp, for example the 5th one, and one for the Ar lamp which should then be number 6. Then exposures [5] – [6] must be executed.

Time: the exposure time in seconds must be entered in this field.

#n: this is the number of times a given exposure is to be repeated.

IHAP identifier: The exposure identification goes in this field. The identifiers of all type `cam` exposures should be identical.

IHAP batch: enter here the name of the IHAP batch to be executed at the end of the exposure. Typically, the batch `KDISPC` to display the image on the IHAP Ramtek is used. This is automatically done in MIDAS.

Setup: in this field the number or the name of the instrument setup table must be entered. The pre-defined instrument setup tables appear in the lower half of the screen, so you don't have to remember or write down what you specified in each of the 6 possible setups for each mode.

Calib. lamp: enter in this field the name or the number of the calibration lamp you wish to use. The list of available lamps is displayed in the TCS Ramtek. Only one lamp should be specified.

In mode DIMD, an extra field **Path** appears in the exposure definition form that should be set to `B` or `R` according to whether the exposure is to be executed in the Blue or Red arms.

The third user area of the exposure definition form is used to set the CCD readout parameters. `Binning x,y` defines the number of pixels that will be combined in each direction. The default is [1],[1] where all the pixels of the CCD are readout independently. If a binning of say 3×3 is specified, the pixel size will be $57 \times 57\mu m^2$ for the TH 1024 CCD and the frame will contain 341×341 pixels plus the ovsercan ones. The next parameter that must be specified is the readout mode. Set the flag in the `Fast readout mode` field to [T] or [F]. In fast readout (T) the readout noise will be significantly larger, but the readout time will be cut by approximately 50%. The conversion factor between ADUs and electrons depends on the readout speed. For slow readout, this factor is $\sim 2/3.3e^-$/ADU (THX/TEK) while for fast readout the factors may be very different. The exact values are periodically measured by the Operations Group and are available at the EMMI control room. A marked noise pickup pattern may be present in bias frames taken in the fast mode. For these reasons fast readout is only recommended for tests and spectral calibrations, but not for your science frames. Also remember that, in general, calibration frames such as bias, flat fields, and darks taken with slow readout cannot be used for correcting fast exposures.

The `window readout` field specifies the geometry of the CCD. If set to [F] the values that appear in the `XL,XR` (Left and Right borders), and `YD,YU` (Down and Up borders) fields are ignored and the full CCD is read out, including the over-clocked columns and rows. The full size of the frame including the overclocked pixels is given between parentheses.

Note:

Remember that if you window the CCD you may loose the overclocked pixels and thus the possibility of checking the actual bias level of your science frames .

The CCD parameters apply to all exposures defined in the form and should therefore be changed before executing an exposure if you wish to use different values for different exposures (e.g. for direct imaging and spectroscopy). In mode DIMD two CCD readout forms appear, one of the red and one for the blue CCDs.

The last field of the form allows to enable the automatic temperature correction of the instrument focus. Set to [T] or [F]. If set to [T] the EMMI camera focus will be automatically set to the value corresponding to the temperature displayed at the top of the form, taking the filter offsets into account.

3.3.2 Executing exposures

To execute an exposure click the `Start exposures` command. This will not be possible if you are still in the exposure definition form. In that case, an error message will appear at the bottom of the Ramtek screen with an audible signal indicating that the mouse is disabled. Exit the form by pressing RETURN or ENTER in the keyboard. Wait for a series of bips and a status message at the bottom of the screen: `Input form no longer active`. Then you may start the exposure. The status of the instrument and CCD will appear on the Ramtek screen. After the instrument is configured, exposure status and integration time information will appear at the upper corners of the screen (upper left for the red CCD; upper right for the blue). This information will appear in every menu so you may safely change forms during exposures and still have information of the remaining time and instrument status. There are several bars in the UIF that allow to pause or abort an exposure, and change the exposure time. In order to prevent accidentally clicking these bars, OBST prompts for confirmation. The command `EMMI & CCD status` provides at any time full information about the status of EMMI and the CCDs. In DIMD, there are separate forms for EMMI (`EMMI status`) and for the CCDs (`CCDr & CCDb status`).

3.4 Acquisition and guiding

The pointing of the NTT is better than 2 arcsec rms. In the direct imaging mode therefore there is no need of checking the field before starting the exposure.

Positioning the target on the slit of the RILD mode is done like in case of the EFOSC instruments. First obtain a short exposure of the object (the use of windowed images and fast read-out is recommended to speed up the procedure). Display the image on either IHAP or MIDAS and use the observing batches `EMPOINT` (IHAP) or `POINT` (MIDAS) to compute the offsets to be given to the telescope to bring the target at the position of the long slit (these positions are measured by the ESO staff and recorded in the EMMI setup form. See Figure 3.1). Appendix A gives a full description of the observing batches available for EMMI observations.

In case that one wants to align the long slit through two objects in the field, the batches `EMROTA` (IHAP) and `ROTATE` (MIDAS) will compute the offset to be given to the adaptor/rotator.

The field orientation in the default position of the adaptor/rotator corresponds to **north at the top, east to the right** in the blue and the red arms. In RILD mode, the long slits are for the same orientation aligned in the north-south direction (dispersion parallel to the CCD rows).

Acquisition of the target for red and blue medium dispersion spectroscopy is normally done with the slit-viewer intensified TV. The scale of the transfer optics is such that 1 arcsec = 2.2 TV lines approximately. The useful field is 2.5×6 arcmin approximately. The limiting magnitude has been measured to be around 19 in the red-visual with seeing of 1 arcsec in a dark night, without frame integration.

The default orientation on the TV viewer is **east to the bottom, north to the right**.

The medium dispersion (MD) slit is oriented **east-west**, but the dispersion is still parallel to the CCD rows.

Two different mirrors project the light from the telescope on the slit depending on whether you work in the blue (BLMD) or red (REMD). The red mirror is a better match to the response of the TV and hence permits usually to see fainter objects. When the instrument is properly aligned, at least in the central part of the field there is a perfect overlap between the images of the slit in red and blue. This enables to use the red mirror to point an object for a blue spectrum. For pointing objects which cannot be seen on the slit viewer one has to determine the apparent position of the medium dispersion slit in imaging mode. To do this, first center a (relatively) bright star on the MD slit using the slit viewer, take an image in RILD, and measure the position of the star on the CCD using `center/gauss` (MIDAS) or `JCEN` (IHAP). Then take an image of the faint (invisible on TV) object and move it to the same pixel coordinates of the bright star using the procedures `EMPOINT` (IHAP) or `POINT` (MIDAS). Then switch back to grating spectroscopy. Remember that although the same slit is used for REMD and BLMD, it does not project onto the same pixels of the corresponding CCDs.

To verify the position of an object on the MD slit before starting an exposure in REMD or BLMD, or simply to inspect the field, one can move the mirrors which reflect the light to the slits by typing from the terminal the command, `OBST > EMMI > MIRR REMD` or `MIRR BLMD`. This can also be done using the soft-key [Show Slit] on the OBST console (not the Ramtek UIF!).

To go back to imaging, one should then type `OBST > EMMI > MIRR RILD` or `MIRR BIMG`.

Guiding the telescope during an exposure is usually done setting on a star with one of the two guide probes in the adaptor and using the autoguider. This operation is normally carried out by the night assistant. In the red and blue medium dispersion modes the guiding, either visually or with the autoguider, can also be done on the image of the field as reflected from the slit jaws and recorded by the intensified slit-viewer TV.

3.5 Focusing the telescope

In the red arm, the focus of the telescope can be determined either using a through–focus exposure sequence, or using a focus wedge similar to EFOSC. Only focus sequences can be used in the BIMG mode. The temperature dependence of the NTT focus is $\Delta F/\Delta T = 0.0764$ mm/°C. The zenith distance correction is neglegible if the active optics system for the main mirror is not in use. Otherwise, it is recommended to check the focus every time the optics are corrected (cf. Appendix F).

3.5.1 Focusing using through–focus sequences

Select the direct imaging modes in either arm. Click the focus parameters bar of the corresponding mode. In RILD, for example, click [`RILD Focus param.`]. A form will appear on the RAMTEK display. The parameters required are the number of focus steps (typically $7-9$), the focus increment (`step size`, typically $10-30\mu$m), and the telescope

offset in R.A. or Dec. (or both; typically 10″). The parameters for the instrument focus are also specified in this form. Here you must give the number of steps, the camera focus offset, and in RILD the starplate offset.

FOC type exposures use the current position of the telescope or camera focus as the value of the middle step of the sequence. Thus, if you want to start at any given focus value, you must position the focus to the value mid-way the sequence. For example, if you want to start at −3.000 mm, the focus of the telescope should be positioned to −2.960 mm for 9 focus steps of $10\mu m$.

The optimal focus may be obtained using the procedures `TFOCUS` (IHAP) or `FOCUS` (MIDAS). The use of these procedures is described in Appendix A.

3.5.2 Focusing with the focus wedge (RILD)

The focus wedge divides the pupil into two halves and separates the two images horizontally by a fixed amount. The vertical separation between the centroids of the two images depends on the defocusing and has been calibrated empirically. For a fair range of focus this dependence is linear, but gets rather complicated if defocusing is severe. To use the focus wedge proceed as follows: take a short exposure image using the focus wedge in the grism wheel and a filter (to minimize atmospheric dispersion). The use of fast readout and windowing is recommended to reduce the overheads. You will see two images for every object in the field. Use the batches `EMFOCUS` (IHAP) or `FOCUS` (MIDAS). These programs, described in detail in Appendix A, give the focus offset to be applied to the telescope. For the reason described above, if the focus offset is large (say more than 0.10mm) it is recommended to repeat the procedure. Normally, two exposures suffice to determine the focus to better than 0.010 mm, which is the accuracy required under good seeing conditions.

The focus wedge works in a parallel beam and, therefore in principle, the focus is the same for all optical elements in the beam. In practice, however, some filters have optical power and therefore introduce focus offsets. The focus wedge is calibrated with no filter in the beam. Offsets introduced by the filters are listed together with the lists of available EMMI filters (Table 2.4). Offsets for other filters can be measured (in RILD only) using the focus wedge with a pinhole mask in the aperture wheel. The batches `EMFOCUS` (`FOCUS`) give the values to be applied to the instrument in encoder units.

The focus wedge should be calibrated and this is normally done by the Operations Group using the Hartmann masks. A quick check may be obtained taking an exposure of the pinhole mask mounted in the slit wheel and illuminated by the He or Ar lamps. In this configuration the focus correction given by `EMFOCUS` or `FOCUS` should be significantly smaller than the values given in Table 3.1. Should this not be the case, call the Operations Group.

Note: *Remember that the focus wedge method works only in RILD mode.*

The telescope focus is the same for the modes RILD, REMD, BLMD if no filters are used under the slit, so the focus wedge can be used for all EMMI configurations except BIMG, for which through focus sequences are in principle required for each filter. However, with

the B filter in the blue arm, the BIMG focus and the RILD focus (no filter or R filter) are the same. The dichroic beam splitter used in DIMD introduces a focus offset in both arms. The value of these offsets is given at the bottom of the instrument setup form (cf. Figure 3.1).

3.6 Focusing the EMMI cameras

The focus of the instrument is normally checked by the Operations Group. The optical set-up form gives the value of the instrument focus for the various modes and their temperature dependence. Only the BLMD mode is critical and the temperature should be closely monitored when working in this mode. Table 3.1 lists the depth of focus of each mode and the corresponding temperature tolerances. These values can be used for average seeing (1 arcsec) conditions where the image FWHM will not degrade by more then about 5% if one stays within the given limits. In very good seeing or with narrow slits these values should be reduced correspondingly.

Table 3.1: *EMMI depth of focus*

Mode	Focus depth (steps)	ΔT(°C)
RILD	22	9
BIMG	55	19
REMD	22	4
BLMD	55	0.7

The temperature of the EMMI room is kept approximately constant by the NTT computer controlled climatization system, so no adjustments to the instrument focus should be required during the night except for mode BLMD. The EMMI temperature is displayed together with the telescope tube and mirror temperatures in the Telescope Control System (TCS) UIF screen which is a RAMTEK monitor located next to the EMMI display.

The focus of any mode can be moved manually from the instrument console using the commands `EMMI >FOCB,value` and `EMMI>FOCR,value` for the Blue and Red arms respectively.

The blue collimator is not perfectly apochromatic so a focus correction will slightly improve the resolution at the extremes of the wavelength range. Table 3.2 gives the focus correction as a function of wavelength with respect to the value given by the temperature equation specified in the set-up form. The best overall focus is obtained at 360 nm.

The instrument focus must be entered in the last field of each of the 6 instrument setup tables. These values will be applied at the beginning of each exposure. The temperature equations are also stored inside the system. Thus, if the automatic mode is selected,

Table 3.2: *BLMD focus correction as a function of wavelength*

λ (nm)	300	320	340	360	380	400	440	480	520
Corr (steps)	-74	−63	−42	−23	−9	0	0	−18	−52

the program checks the EMMI temperature, calculates the focus, and applies the filter offset. This, however, is done by the program only at the beginning of, but not during, an exposure.

3.6.1 Checking the EMMI focus yourself

The EMMI focus is usually determined by the Operations Group but, should you want to check the relations given, the following procedures may be followed. Use one of the internal lamps. Typically exposures of a few seconds with He or Ar are sufficient.

RILD: do a through-focus exposure using the test starplate which has holes of $\sim 200\mu m$ diameter through the R filter and run `TFOCUS` (IHAP) or `FOCUS` (MIDAS). Remember to select exposure type `foi` and to fill the `RILD Focus param.` form. You may also take an exposure with the focus wedge to test its adjustment. The focus positions found with the two methods should coincide to within 10 encoder steps.

BIMG: a special test starplate must be mounted by the Operations Group. Take a series of 4 exposures with different focus positions through the B filter and load them on the RAMTEK in split screen mode, then run `TFOCUS`.

REMD and BLMD: set the slit to $\sim 1''$ and do a through-focus exposure on the slit with the grating in the zero–th order ($\lambda = 0$). It is also possible to do a through-focus exposure on a spectrum; in this case use a spectral lamp and set the grating to the desired wavelength.

Note: *echelle grating #10 cannot be stepped; here 4 sequential images with different focus settings must be taken and analyzed as in BIMG. Use the Th-Ar lamp.*

3.7 Multi-object spectroscopy (MOS)

The MOS mode of EMMI (RILD) is very similar to that of the EFOSC instruments described in Melnick et al. (1989). Table 3.3 compares the capabilities of EMMI with EFOSC1 (3.6m telescope).

The EMMI starplate wheel has 5 positions one of which is always kept free for direct imaging. Thus, for MOS work up to 4 of the regular long–slit plates can be replaced by starplate blanks. Any remaining regular long–slit plate will be protected by the software in order to prevent accidental punching. The punch heads of EMMI produce rectangular

slitlets of the dimensions indicated in Table 3.3. Long slits may be created by punching several adjacent slitlets.

The installation of blank starplates takes only a few minutes, but is a delicate operation which must be done by the Operations Group. Changing punching heads is time consuming and cannot be done during the night. The procedure that must be followed to punch MOS plates (also called masks) is given below.

Table 3.3: *Comparison of MOS modes in EMMI and EFOSC1*

	EMMI	EFOSC1
Wavelength range (Å)	4200 – 10000	3600 – 10000
Imaging field (arcmin)	7.5 × 7.5 (THX1024 CCD)	5.1 × 5.1 (TEK512 CCD)
Punch field (arcmin)	5 × 8	3.6 × 4
Aperture shape	Slit	Circ. hole
Size (arcsec)	1.3 × 8.6 1.9 × 8.6	2.1 diam. 3.6 diam.
No. objects per field	10 – 30	10 – 30
Punching machine	On line (on EMMI)	Off line (control room)

1. Obtain a direct image of the field. Notice that the grisms deviate the beam and therefore that the wavelength range covered by MOS spectra depends on the X position of the slit. Table 3.4 gives the approximate wavelength coverage for the 6 EMMI grisms as a function of slit position. The software used to prepare MOS plates has an option to show the area of the image where objects may be selected in order to cover a given spectral range.

2. Using `MIDAS` context `EMOS` defines the positions where the slitlets will be punched. EMOS uses a mouse driven X11 graphical user interface and is straightforward to use. A detailed description is provided in Appendix A.

3. Click `Multi Obj. Spectr.` in the RILD mode menu. A group of new bars will appear. Click `Define Filename`. A form will appear where you should fill the names of the files containing punch coordinates produced by EMOS. Then click `Punch Starplate`. You will be prompted for the mask to be punched. Fill-in the number and press return. The EMMI and CCDs stati will be displayed on the UIF. Progress information is given at the bottom of the form and in the EMMI console.

4. Make a short exposure of the mask using one of the internal lamps (i.e. a `cal` exposure using typically the He or Ar lamps). Since some filters may introduce

small offsets, make sure to image the MOS plate through the same filter used to image the field. Most filters have offsets between 0.3″ and 0.5″. The R filter has an offset of only 0.1″ and is therefore recommended. Working without filter may lead to less accurate results due to differential refraction, but reduces considerably the exposure times and is thus recommended for very faint objects.

5. Point the telescope to the field and take a direct image. To save time, it is recommended to return to exactly the same position where the image used to punch the MOS plate was taken. This may be achieved by writing down the positions of the telescope, of the rotator, and of the guide probe when the images of the field are taken. In that way you may return to the same guide star.

6. Use the procedures `EMPOINT` (IHAP) or `POINT` (MIDAS) to align the starplate and field images. This is achieved by offsetting the telescope to the position of one of the slitlets (previously measured on an image of the mask taken with one of the internal lamps). Thus, it is recommended to punch 2 – 3 single slitlets at the position of (bright) stars to facilitate alignment.

Punching MOS plates is most efficiently done during the afternoon using images taken the previous night. Starplates may also be prepared during long exposures, but the RILD mode may not be used during the actual punching procedure which may take between 5 and 15 minutes depending on the number of slits and their positions. Notice that there is some play in the starplate support so *a mask that is removed and mounted again may no longer be aligned with the image used to define the slit positions.*

Table 3.4: *Spectral coverage in MOS observations as a function of X position of the target (for THX1024 CCD and F/2.5 camera).*

Offset (arcmin)	ΔX (pixels)	1	2	3	4	5	6
−2.2	−300	3900 – 11000	4980 – 9665	4650 – 9750	6665 – 11000	4780 – 6990	6680 – 8640
−1.5	−200	3900 – 11000	4460 – 9200	4745 – 8590	6200 – 10820	4560 – 6770	6480 – 8440
0	0	3900 – 11000	3900 – 8255	4040 – 7830	6280 – 9900	4120 – 6330	6090 – 8050
1.5	+200	3900 – 8680	3900 – 7320	3900 – 7080	5800 – 8980	3900 – 5890	5690 – 7650
2.2	+300	3900 – 7660	3900 – 6860	3900 – 6700	5800 – 8520	3900 – 5670	5500 – 7460

3.8 Calibration exposures

3.8.1 Spectroscopy

There is a system of calibration lamps associated with the adaptor/rotators at the NTT which can be used for most of the calibrations required for the EMMI data. The lamp system is controlled by the telescope (NTT) computer, but calibration exposures can be fully set up from the EMMI control software.

The main component of the calibration system is an integrating sphere mounted on the side of the adaptor. Light from the output aperture of the integrating sphere passes a lens and is reflected to the center of the focal plane by a 45° mirror which is moved to the optical axis. On the integrating sphere He, Ar, and ThAr lamps are mounted, while the light of flatfield and other spectral lamps that are mounted in a rack on the floor is fed to the sphere through an optical fibre. The angular size, location, and shape (including central obscuration) of the NTT exit pupil are approximately simulated. The illumination is homogeneous and unvignetted in a 3×6 arcmin field (still usable in a field of $5' \times 8'$). The slit length or field is $6'$ in grating spectroscopy and up to $8' \times 5'$ for MOS, so the lamp system is well suited for spectral flatfields. Typical exposure times for the He-Ar and Th-Ar lamps used for spectral calibrations are given in Table 3.5. These values should only be used as first guesses, as the actual exposure times may change as the lamps age.

Table 3.5: *Reference exposure times for wavelength calibrations*.*

Grisms	He+Ar	Gratings	He+Ar	ThAr
		RED		
#1	$3.5s + 0.5s$	# 6 @5500Å	$10s + 180s$	not useful
#2	$5s + 2s$	# 7 @6000Å	$10s + 180s$	not useful
#3	$6s + 3s$	# 8 @6200Å	$10s + 180s$	not useful
#4	$6s + 1s$	# 9 all grisms	not useful	$10s$
#5	$2s + 60s$	#10 all grisms	not useful	$10s$
#6	$5s + 1s$	#13 @5500Å	$10s + 240s$	not useful
		BLUE		
		# 3 @3800Å	not useful	$60s$
		# 4 @4150Å	20s+60s	
		# 5 @3700Å	$10s + 60s$	not useful
		#11 @3500Å	not useful	
		#12 @3500Å	not useful	

* Slit 1".5 wide

3.8.2 Direct imaging

Flatfielding in direct imaging, which has a larger field, is best done on the sky during morning and evening twilight. For broad-band filters this is possible for about 30 minutes around $-12°$-twilight; narrow-band and U exposures can be done close to sunrise and sunset. Sky flats are also recommended to determine the slit function for long-slit spectroscopy. There are also dome lamps that can be used to take dome flatfields; the night assistant, the Operations Group, or the introducing astronomer can assist the visitor in their use.

3.9 Exposure times

3.9.1 Shutter timing

Because of the mechanical constraints in the instrument, the EMMI shutter is rather slow. Delay times of 0.5 – 0.6 seconds have been measured in the blue and red cameras. The accuracy of the measurement is about 10 ms. Because of the location of the shutter in the optical path, the exposure time over the field is constant and equal to the chosen time plus the average shutter delay which is given in the file header. If critical for your application, it is recommended that you check the shutter timing by either taking exposures of increasing duration on a star, or using one of the internal lamps and a pinhole in the apperture wheel.

3.9.2 Typical count rates for direct imaging

Table 3.6 gives the measured performance of the EMMI modes RILD and BIMG for broad-band imaging. The figures give the total efficiency of the system and the corresponding count rates for a star with approximately zero colours.

Table 3.6: *Efficiency of EMMI and SUSI for direct imaging.*

Filter	Telescope + instrument efficiency (%)			Count rate (e^-/s) for 15th magnitude A-star		
	RILD	BIMG	SUSI	RILD	BIMG	SUSI
U	—	—	—	—	—	—
B	—	—	10	—	—	1.1×10^4
Bb	4	—	—	6×10^3	—	—
V	16	—	21	1.7×10^4	—	2.2×10^4
R	20	—	28	2×10^4	—	2.8×10^4
I	12	—	—	6.8×10^3	—	—

3.9.3 Colour equations

Approximate colour equations for the Bessel filter used in EMMI and SUSI are given below. These should only be used to obtain approximate photometry on frames taken for other purposes (e.g. pointing) but should not be used for accurate photometry since the stability of the instrumental system has not been verified.

EMMI - RILD

$$\text{B–b} = 0.13 \times (B - V) + 23.72$$
$$\text{V–v} = 0.03 \times (B - V) + 25.03$$
$$\text{R–r} = 25.00$$

SUSI

$$\text{B–b} = 0.14 \times (B - V) + 24.81$$
$$\text{V–v} = 0.02 \times (B - V) + 25.44$$
$$\text{R–r} = 25.66$$

3.9.4 Typical count rates for spectroscopy

The measured count rates in spectroscopic mode are given in Table 3.7 for grisms and Table 3.8 for gratings. The values given in these tables were obtained from observations of the spectrophotometric standard LTT 9239 through wide slits (10″ for grisms; 9″ for gratings) on a photometric night, and at an airmass very close to unity.

Table 3.7: *EMMI performance for grism spectroscopy (RILD mode).*

Grism	λ (nm) 400	450	550	650	750	800	900	1000
	count rate (e^-/sec)							
1	60	310	1100	1300	650	470	210	40
2	50	190	550	620	300	20	—	—
3	—	100	450	470	230	0	—	—
4	—	—	0	490	370	280	140	0
5	0	70	210	0	0	—	—	—
6	—	—	0	190	110	80	—	—
LTT 9239 approx. magnitude	12.8	12.4	12.0	11.8	11.7	11.6	11.6	11.6

The efficiency curves given in Appendix B, in Figure 2.7, and in reference [1] can be used to interpolate the values given in Tables 3.7 and 3.8 to other wavelengths.

Note: *Do not forget to consider seeing effects when estimating exposure times for narrow slit observations.*

Table 3.8: *EMMI performance for grating spectroscopy.*

Grating	λ	Count rate (e^-/sec/pix)	Approx. mag. of LTT 9239
3	3800	65	13.2
5	3800	6	13.2
6	5500	40	12.1
7	6000	100	11.9
10+grism 6	5240	2000	4.6*

* HD 4468

3.10 Format of the scientific data

The data from the EMMI and SUSI detectors are simultaneously transmitted to the IHAP and the MIDAS stations. MIDAS runs on a SUN workstation equipped with an Exabyte 8200 8mm tape unit. IHAP uses standard 1/2 inch 2400 foot tapes at 6250 BPI with a total capacity of 45 1024 × 1024 images in FITS format. A 90 min Exabyte tape can store close to 1000 frames.

The FITS format is strictly according to the ESO policy to archive fully the EMMI data and make them later available to the general users. The FITS headers of CCD files contain all the information necessary for the scientific use of the data, that is all the telescope, instrument, and detector parameters have the time information. At present, archiving is done using the IHAP system. Thus, observers are requested to save their data using IHAP even if they use the Exabyte storage concurrently. Notice that the full header information is not stored in the IHAP header, but in FITS keywords. Therefore, the softkey `LIST FITS KEYS` must be used instead of `DLIST` to display the information on the IHAP terminal. The Exabyte tapes are not archived, and it is the observers responsibility to manage these tapes. 60 and 90 minute 8 mm video cassettes can be obtained from the Astronomy Secretary on La Silla. Note that while IHAP stores the data with 15-bits of precision (0 – 32768 ADUs), the full 16-bit precision delivered by the CCD cameras (0 – 65536 ADUs) is preserved in MIDAS.

Chapter 4

Observing with SUSI

The Superb Seeing Imager (SUSI) is physically distinct from EMMI but complements its observing capabilities. A supporting plate is mounted on the adaptor of the Nasmyth A focus of the NTT. On the plate, a mirror with 3 positions is mounted. The first position sends the light to SUSI, the second feeds an IR camera (not available), and the third position is free for the operation of IRSPEC. A CAD view of the assembly (called the Direct Imaging Facility, DIFA) is presented in Figure 4.1. Between the diagonal mirror and the CCD is a filter wheel with 8 positions.

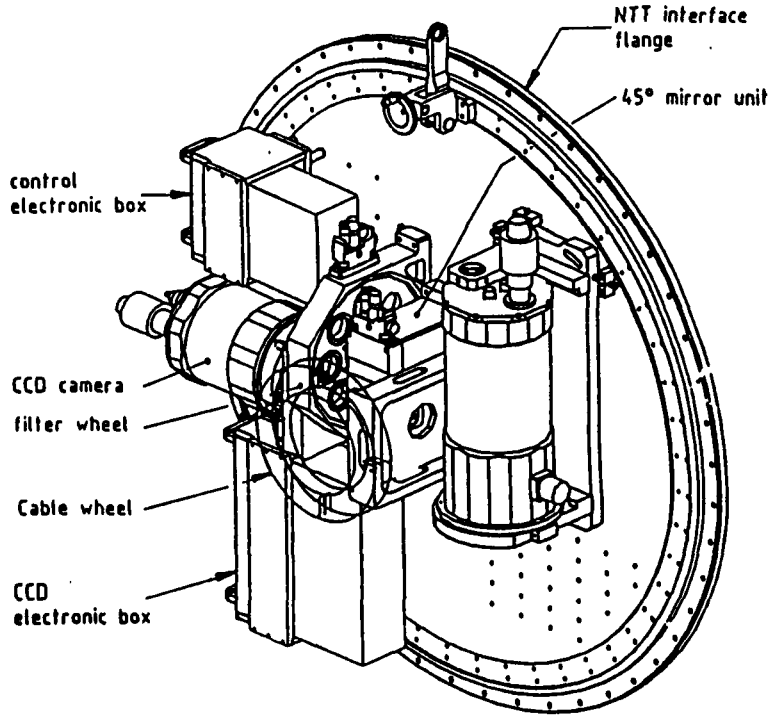

Figure 4.1: *CAD drawing of SUSI identifying its major components. The second dewar shown in the figure corresponds to an IR array camera.*

SUSI uses a TEK CCD (ESO #25) with 1024 × 1024 pixels of 24μm corresponding to 0.13″ on the sky. The field of view is thus 2.2 × 2.2 arc minutes. More details about the CCD can be found in the ESO CCD manual and in the MIDAS context FILTERS.

4.1 SUSI filters

The filter wheel of SUSI accepts up to 8 filters 60mm in diameter. There is a basic set of filters for SUSI which are listed in Table 4.1. Other filters may be selected from the ESO filter catalogue. In particular, the EFOSC filters fit SUSI directly without the need of special adapters.

Table 4.1: *SUSI filters: basic set*

ESO #	Filter	Focus offset
640	U	
639	B	
641	V	0
642	R	
703	g	
704	r	
705	i	
706	z	
707	OIII	
708	Hα	
709	Hαr	
710	SII	

4.2 SUSI control software

In order to allow simultaneous operation of SUSI and EMMI, SUSI is normally run using two terminals on the IRSPEC side of the NTT control room. One terminal (LU:54) is used for SUSI and the other (LU:62) for IHAP, in the same way as for EMMI. To start the SUSI control programme, log-on with username SUSI (no password required) and follow the instructions that will appear on the screen. As EMMI, SUSI uses a mouse driven graphical interface on a Ramtek monitor. After SUSI starts, the Ramtek UIF displays a number of bars on the right hand side. Click `SUSI observations`. A number of new commands will appear. The command `Define Exposures` allows you to define up to 8 exposures in the same way as for EMMI. Only 4 types of exposures, however, exist for SUSI: `dk` (dark), `sci` (scientific), `ff` (flat field), and `foc` (focus exposures). The list of filters mounted on the filter wheel (up to 8) appears on the form, and can be selected by number or by name. The `Start exposures` command is used to start the sequence defined in the form.

4.3 Focusing the NTT with SUSI

Telescope focus is critical to obtain good images. The slow angle of the NTT beam at the Nasmyth focus (F/11) facilitates focusing the telescope with SUSI, which must be done using through-focus sequences. The parameters for these sequences are entered in the **SUSI Exposures** form. Tests done on reasonably good seeing ($0.75'' - 1.0''$) showed that the optimal focus step is 30 microns. Step the telescope by $\sim 10''$ in the most convenient direction depending on the field. 7 – 9 focus exposures give the best results. The observing batches TFOCUS (IHAP) or FOCUS (MIDAS) can be used to measure the focus sequences.

The following table gives focus values for the most used SUSI filters. Notice, however, that these values are preliminary and should only be used as initial guesses for your focus sequences. The NTT focus changes with temperature as $\Delta F/\Delta T = 0.0764$ mm/$^\circ C$. If the main mirror is activated, it is recommended to check the focus every time a correction is made (cf. Appendix F).

Table 4.2: *Indicative SUSI telescope focus for $T = 10^\circ C$*

Filter	Telescope focus (mm)
U	−3.48
B	−3.47
V	−3.50
R	−3.47
I	−3.43
Z	−3.43

To speed up focusing of SUSI the following initial guesses may also be useful:

focus[SUSI(V)] = focus[RILD(R)] − 0.26
focus[SUSI(V)] = focus[Image analysis side A] − 0.10

Chapter 5

Additional Information about EMMI

5.1 Ghosts and image anomalies

5.1.1 Imaging (RILD and BIMG)

Most ghosts in imaging are due to a reflection between the CCD and a lens surface, and as such, they depend on the reflectivity of the CCD surface and the efficiency of the antireflection coatings. The antireflection coatings on EMMI have a low reflectivity (1% in the red and 0.4% in the blue, compared to 2% for EFOSC). On the other hand, the reflectivity of the present CCD, the THX 31156 Thomson is higher than that of other CCDs. Therefore, the sky concentration already familiar from EFOSC is also present in EMMI. This type of effect is very difficult to avoid in any focal reducer design. It is due to light — from the sky background and from stars — that is reflected back into the camera by the CCD and returned by some optical surfaces. We used a special technique to measure the sky concentration in red imaging, as the modulation is less than 1%, the effect is not very noticeable in normal flatfield exposures. In the centre of the chip, we measured a level of scattered light of about 2.5% of the background in the B band, which decreased gradually to 1.2% in Z. At the edge of the chip, levels are about 1.6% and 0.8%. No measurements were taken in the blue.

An on-axis star has a faint halo around it with an intensity level dropping to 10^{-4} at 5 pixels from the parent star (RILD). This was measured without any filter in the beam.

In RILD, filters are tilted so reflections between the CCD surface and the filter are excluded (see section 5.3 for a discussion of the effect on the filter spectral properties). However, multiple reflections inside the filter may in principle lead to satellite images close to the parent if the filter has a small wedge. No such ghosts with a level greater than 10^{-3} were found for filters 587 to 645. In BIMG, filters are in the converging beam and no nearby in-focus ghosts are expected.

5.1.2 Spectroscopy (RILD, REMD and BLMD)

Image ghosts and anomalies may originate from both the grating (or grism) and the spectrograph optics.

Grating ghosts are caused by periodic variations in the position of the grooves. Long-periodic errors of the grating engine produce line satellite (Rowland) ghosts which perturb the line shape and so may change the width and shape of the point spread function. The observer should be very careful in looking for faint or unidentified lines, especially when observing objects with strong emission lines, because these might be the more dangerous Lyman ghosts. These are far away from the parent line and are caused by short-periodic errors of the ruling engine. According to manufacturers' specifications, all EMMI gratings have Lyman ghosts $< 10^{-4}$ except No. 6 (3.8×10^{-4}), No. 7 (1.8×10^{-1}) and No. 9 (17×10^{-4}).

The efficiency curves of some gratings show irregularities called Wood's anomalies. These anomalies depend strongly on the polarization of the incident light and are most prominent when the polarization is perpendicular to the grooves. Wood's anomalies affect gratings numbers 3, 7, 8 and 11.

The curved cemented surface inside one of the doublets of the red collimator happens to be exactly perpendicular to the incoming diverging beam. It is effectively behaving like a plane parallel glass plate in front of the grating (however with a very low reflectivity of about 4×10^{-4}). The white light ghost image of the slit generated by this surface was moved outside the CCD field by applying a small tilt to the collimator. A complementary ghost is formed by light that is dispersed by the grating, reflected by the cemented surface and dispersed a second time. This appears on the CCD as ghosts of a few times 10^{-4} of bright emission lines that are in the right–hand half of the CCD image, located approximately twice as far from the right–hand edge of the CCD as their parents. So far we only noticed ghosts in calibration echelle spectra, where some of the bright Ar lines of the ThAr calibration lamp produce ghosts of this type.

Interorder stray light was measured with grism #3 as cross–disperser and the red flatfield lamp. The absolute level is highest near 7000Å and reached 1.9% of the continuum with echelle grating #9. With #10 the stray light level was 6% of the continuum at 7500Å. On request, a stray light mask can be mounted in the intermediate focal plane (between the collimator and the focal reducer). This reduces the stray light level to 1.2% and 3 %, respectively.

A stray light gradient which does not depend on the continuum intensity is present when combining echelle grating #10 with grism #3 as cross–disperser. The stray light is strongest near the top of the CCD with a level of about 50 e^- in a 1 hour exposure. The effect was only observed with grism #3 and was not noticed with grism #4 as cross–disperser. The stray light seems to be generated inside the transfer collimator and its cause will be further investigated.

The main LED panel display on EMMI should normally be switched off (be careful, the switch "status display" is sitting next to the master power switch!). There are some status display LEDs on the racks and adapter that cannot be switched off. With the lights in the instrument room turned off, no light leaks have been noticed in EMMI in exposures of up to 3 hours.

The blue mirror train shows a 10% reflectivity dip with a width of about 50Å in one polarization at around 370 nm, which could easily be mistaken for an absorption feature. The antireflection coatings of the red lenses also show some dips that are however not polarization-dependent and several 100Å wide.

The dichroic prism shows large variations in the efficiency in the polarization perpendicular to the slit up to 30%. The region between 400 and 480 nm is heavily polarized and it is not recommended to use the dichroic prism on polarized objects.

Efficiency variations normally flatfield out for nonpolarized objects. The observer must take extra precautions when studying strongly polarized objects.

5.2 Image quality, scale and distortion

5.2.1 Imaging

The measured scales determined using stars in an astrometric field are 0.4397 ± 0.0005 arcsec/pix in the red, and 0.286 ± 0.001 arcsec/pix in the blue (THX1024 CCDs were used in both arms). For a pixel size of 19μm, this corresponds to 43.2 and 66.4μm/arcsec in red and blue, respectively.

The above coefficients are but the first terms in the polynomial that describes the transformation from sky to pixel coordinates. Higher order terms must take into account lateral colour (chromatic variation of focal length) which goes with the first power of the radial distance, and 3rd and 5th order distortions. The total contribution of these terms is less than 25μm at 17.5 mm from the centre of the CCD.

Spot diagrams in RILD for the F/2.5 and F/5.3 cameras, and BIMG are given in Figures 5.1, 5.2, and 5.3. These were calculated assuming a perfect telescope and atmosphere. In RILD the image quality (80% energy concentration) is better than 10μm in most of the field and better than 20μm out to the corners. In BIMG the image quality is better than 20μm in most of the field.

The on-axis image quality that was actually achieved, was measured by imaging a starplate with pinholes of different sizes in the telescope focal plane onto the CCDs and measuring the FWHM of the image. The instrument PSFs found (FWHM of 0.48 arcsec (1.1 pix) in the red and 0.37 arcsec (1.3 pix) in the blue) are clearly dominated by the pixel size. (The THX1024 CCD and F/2.5 camera were used in these measurements). In the case of blue wavelengths, photon emission from the coating does also degrade the image quality. Thus, a 0.7″ image delivered by the telescope to the Nasmyth focus is e.g. degraded by EMMI to 0.84″ in the red and 0.79″ in the blue.

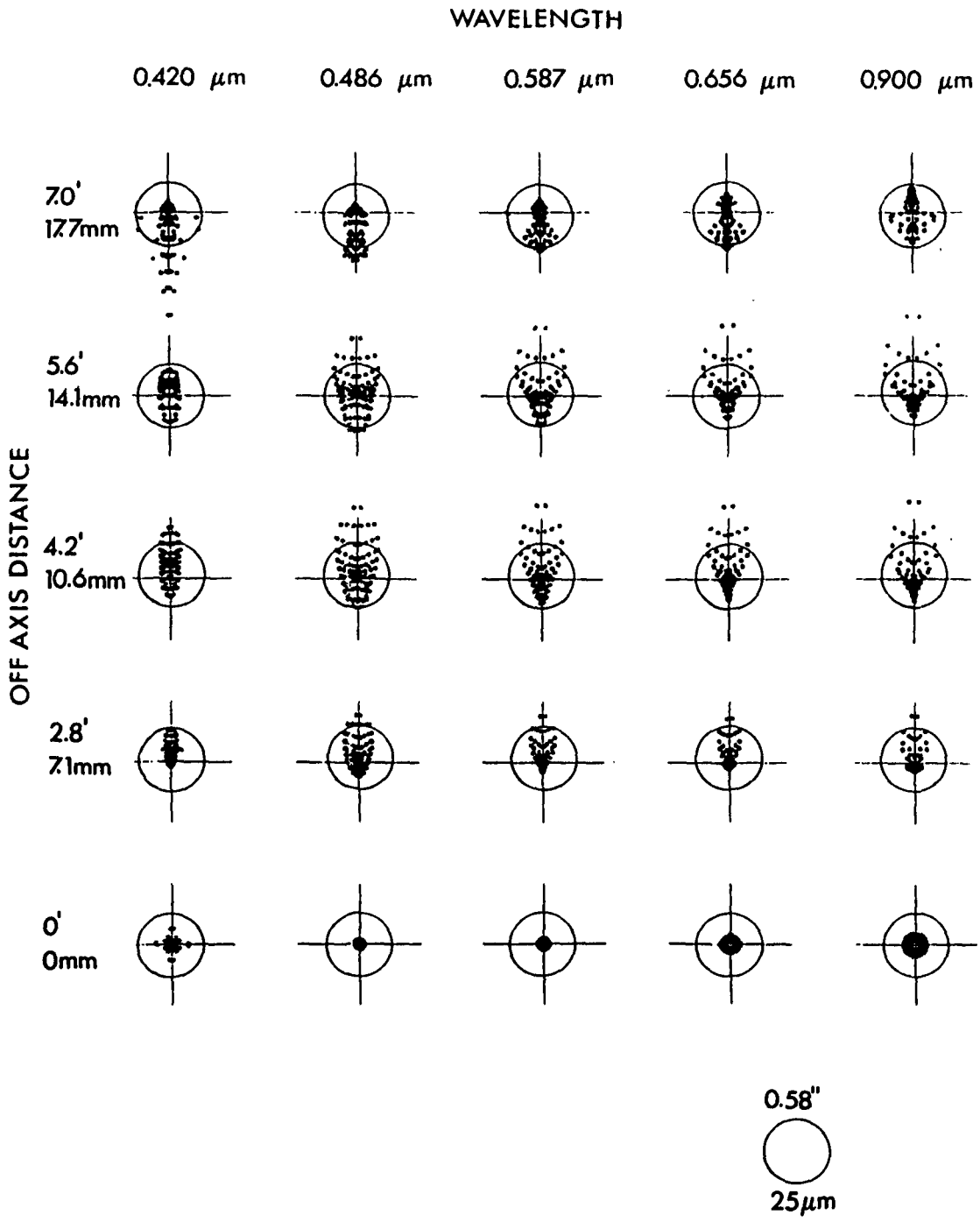

Figure 5.1: *Spot diagram showing theoretical image quality in RILD with the F/2.5 camera, at a single focus setting at various wavelengths and radial field points.*

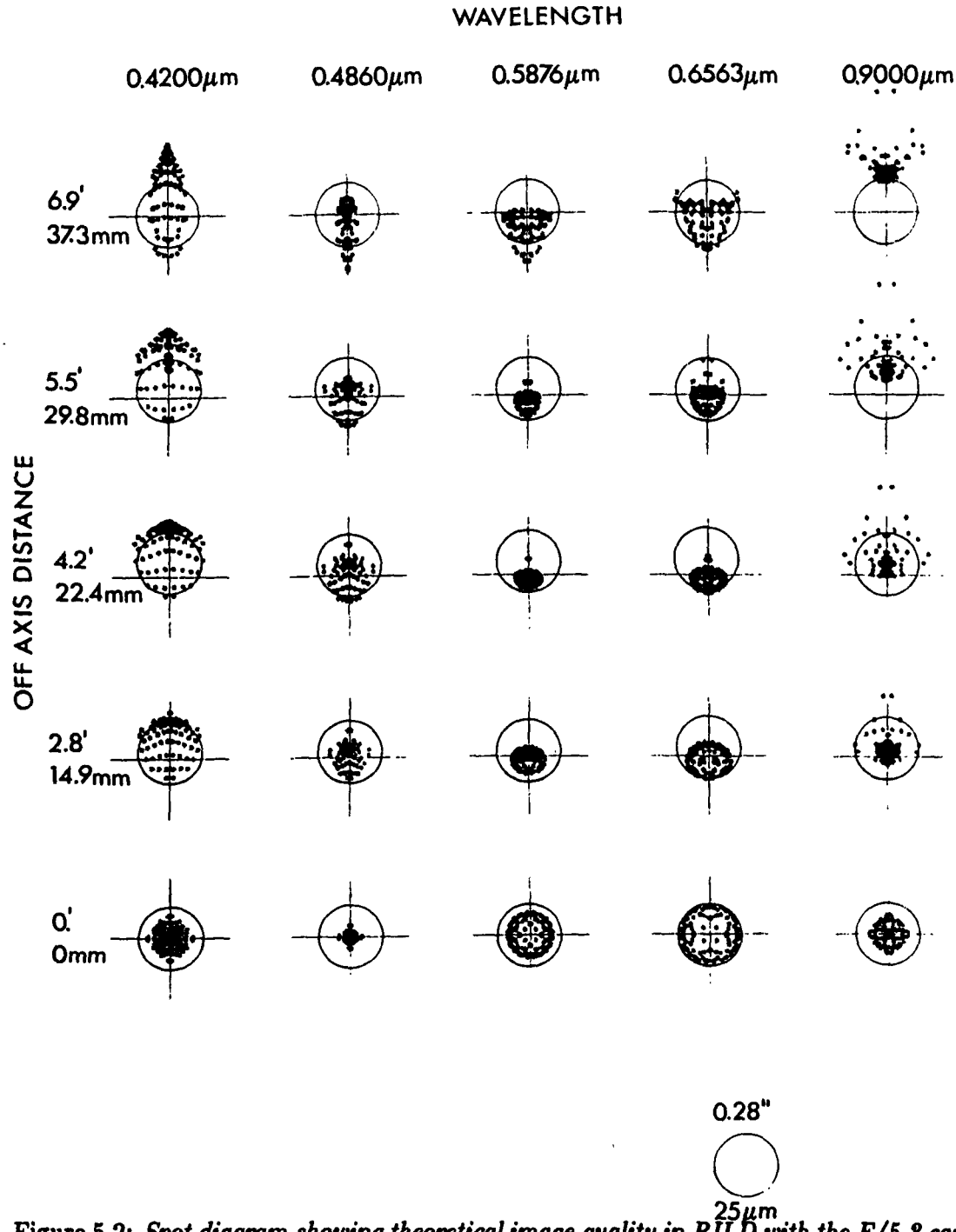

Figure 5.2: *Spot diagram showing theoretical image quality in RILD with the F/5.3 camera, at a single focus setting at various wavelengths and radial field points.*

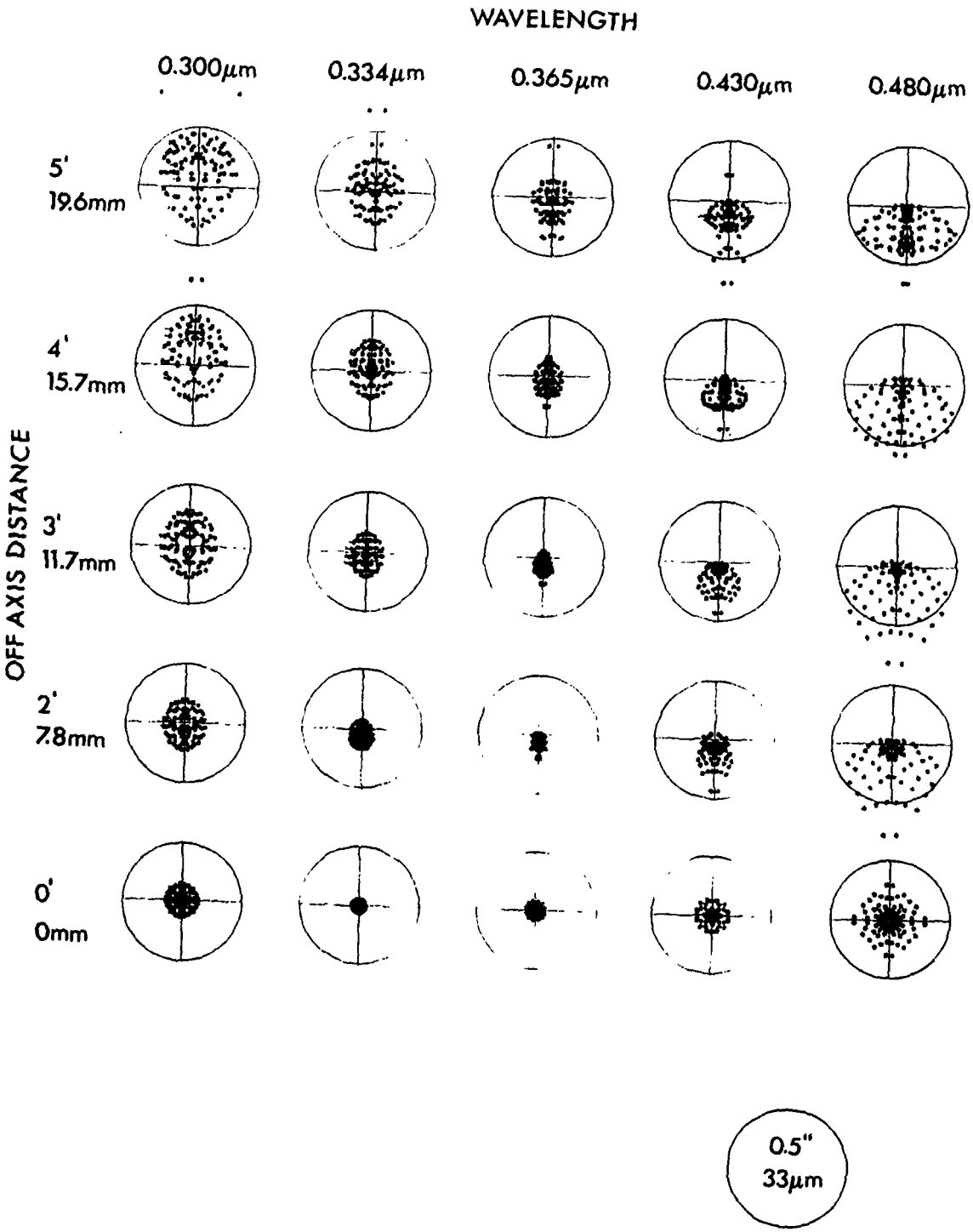

Figure 5.3: *Spot diagram showing theoretical image quality in BIMG with the F/4 camera, at a single focus setting at various wavelengths and radial field points.*

The spot diagrams show that optical aberrations and lateral colour produce image elongations in the field that cannot be neglected. Note that the elongation axis direction varies with field position. Other possible factors contributing to image elongation are: sampling effects in the CCD, filter image quality, atmospheric dispersion and telescope tracking including wind buffeting effects and field rotation. Most of these produce an elongation that is constant in the field. Image size differences of 0.1″ in X and Y on 1″ images are normal and do not necessarily point to telescope tracking errors.

5.2.2 Spectroscopy

The image scales given for imaging also apply to EMMI used in spectroscopy. High-angle grisms and gratings produce anamorphosis which results in a slit image that is narrowed (the usual case) or widened by a certain factor. The scale along the slit is not affected. At the CCD centre, the anamorphic factor A is equal to:

$$A = \frac{\cos(\theta + \frac{\phi}{2})}{\cos(\theta - \frac{\phi}{2} + \psi)},$$

where ϕ is the angle between incident and diffracted beams at the field centre, θ the grating angle and ψ the field angle. For gratings we have:

$$\theta = \frac{arcsin(n \times m \times \lambda)}{2 \times 10^{-7} \times \cos\frac{\phi}{2}},$$

where n is the number of grooves/mm, m the order, λ the wavelength in Å. $\phi = 5.5°$ in EMMI while $\psi = arctan\frac{x}{120 \times F\#}$, where x is the distance in the CCD focal plane from the field centre in mm and F# is the camera speed.

Gratings #9 and #10 have $\theta = 28.7°$ and 63.5°; the anamorphism is 0.96 and 0.82, respectively.

Grisms have A = 1 at the central wavelength, A > 1 towards the red and A < 1 towards the blue. Here we have:

- $\theta = 40°$ for grism #6 and 26° for grism #5 (less for other grisms)
- $\phi = 0°$
- $\psi = arctan\ (\frac{x}{50 \times F\#})$, where x is the distance from the field centre in mm.

In the case of grism #6, A = 0.94 at the red end of the spectrum and A = 1.07 in the blue. Grism #5 has less anamorphosis with A = 0.97 and 1.04, respectively. The anamorphosis for other grisms is less.

If grisms are used as cross–dispersers in echelle spectroscopy, the scale in the slit direction will be affected: in the case of grism #6 for instance, the height of the spectrum is 14% smaller in the red orders than in the blue.

With high-angle grisms and gratings, long slit spectra will show spectral line curvature. Spectral lines have a parabolic shape with shifts towards the blue at the upper and lower edges of the slit of up to to several pixels depending on the grating used and the wavelength settings. The long-slit spectral reduction package SPECTRA in MIDAS automatically corrects this distortion.

5.3 Filter properties

All filters are permanently mounted in their cells. Although it is possible to use blue filters in the red and vice versa (for example in the overlap region; 4000 to 5000 Å), filters should normally be used on the wheel they are intended for. Blue filters are mounted at 0 degrees in their cells while red filters are at 5 degrees to avoid reflections between the CCD and the filter. Below slit filters are glued in a rectangular cell that only permits to use them on one of the two below slit wheels of EMMI.

As a general rule, all filters are blocked to better than 10^{-4} to 1.2μm. Note that the blue arm of EMMI provides some additional blocking to red light: 10% beyond 6000 Å and less than 2% between 8000 Å and 1.2μm.

The spectral properties of colour filters are to a great extent independent of the angle of incidence and can be assumed to be constant within the field, both in blue and red imaging. The central wavelength of interference filters shifts to the blue if this angle deviates from 0 degrees. The following formula applies:

$$\lambda = \lambda_0 \sqrt{\frac{1 - \sin^2 \phi}{n}},$$

where ϕ is the angle and n the effective refractive index of the material forming the spacer cavity. The EMMI blue filters are placed in the diverging F/11 beam in front of the blue camera, so the effective filter curve (averaged and weighed for all incidence angles in the F/11 cone) will be somewhat broadened and blue-shifted compared to the filter curves measured at 0 degrees incidence. The effects are likely to be on the order of only a few Å in the blue and may be neglected with the bandpasses used in the current set (> 50 Å FWHM).

The EMMI red filters are placed in the parallel beam between the collimator and the camera. The angle of the beam with the optical axis depends on the field position of the object, and is for instance 4.5 degrees for a field point on the edge of the Thomson chip (F/2.5 camera, F/125 mm). However, red filters must be tilted 5 degrees in order to avoid reflections between the filter and the CCD, and so the angle of incidence is 0.5 degrees at the lower edge of the chip and 9.5 degrees at the upper edge. The effect on the bandpass of filter #601 has been measured at incidence angles between 0 and 15 degrees, and a value of $n = 2.06$ has been found. The wavelength shift is significant: about 0.3% of the central wavelength (30% of the FWHM: 22Å) at 9.5 degrees in the case of #601.

Observations are affected in two ways. First, observers should remember that filter central wavelength, and to a lesser extent also FWHM, are field-dependent and take account of this, for instance by positioning critical objects nearer to the lower edge of the chip. Secondly, bright sky emission lines that are not in the filter passband at edge of the field may be just in at the other edge, giving rise to a background slope which then requires additional attention to flatfielding.

U and B photometry should normally be done in the blue arm of EMMI. The Bb (blue B) filter is a B filter intended for use in the red arm of EMMI, and is open towards the UV in order to approximate the regular B as well as possible. The red optics of EMMI have a sharp cut–on at 3900 Å due to the coatings, and so the effective central wavelength/bandpass of the Bb filter is 4295/790 Å as opposed to 4230/940 Å for the B filter used in the blue arm of EMMI. We expect that better results (efficiency and colour transformation coefficients) will be obtained with the B filter, but no systematic study has been made so far.

Since the blue and below slit filters are used in diverging beams, they affect the focus. The red filters are used in parallel beam and introduce no significant defocus in most cases. The below slit filters are normally used with a wide slit for flux calibration on standards, where it is not important to achieve the optimum spectral resolution, so no focus correction is necessary.

The image quality of some filters was investigated by imaging a 200μm (1.07″) pinhole in a starplate. The geometrical size of the image on the CCD corresponds to 3.8 pix in the blue and 2.4 pix in the red. There is some evidence of image degradation by filters #588 and #606. Some improvement may be expected by refocusing, as the focus was set at the optimum found for the B and R filters. No nearby ghosts could be identified down to a level of 10^{-3}.

If a blue filter is used in the red arm, every object in the field produces a ghost which is about 5 magnitudes lower in brightness, located on the opposite side of the optical axis. A red filter used in the blue will cause some astigmatism.

5.4 Image stability and flexure

EMMI rotates with the adapter to follow field rotation. Depending on the duration of the exposure and the location of the object, instrument rotations of 180 degrees and more may result. The instantaneous angle is displayed by the instrument control program.

Instrument flexure has been measured in REMD and BLMD with a 1″ decker on the slit and a test mirror instead of the grating. The position of the image on the CCDs was measured at various adaptor angles and the results are displayed in Figure 5.4. In all cases, hysteresis was smaller than 0.1 pixel indicating elastic behaviour. The peak to peak excursion in the dispersion direction is 0.3 pixels in REMD and 0.35 pixels in BLMD.

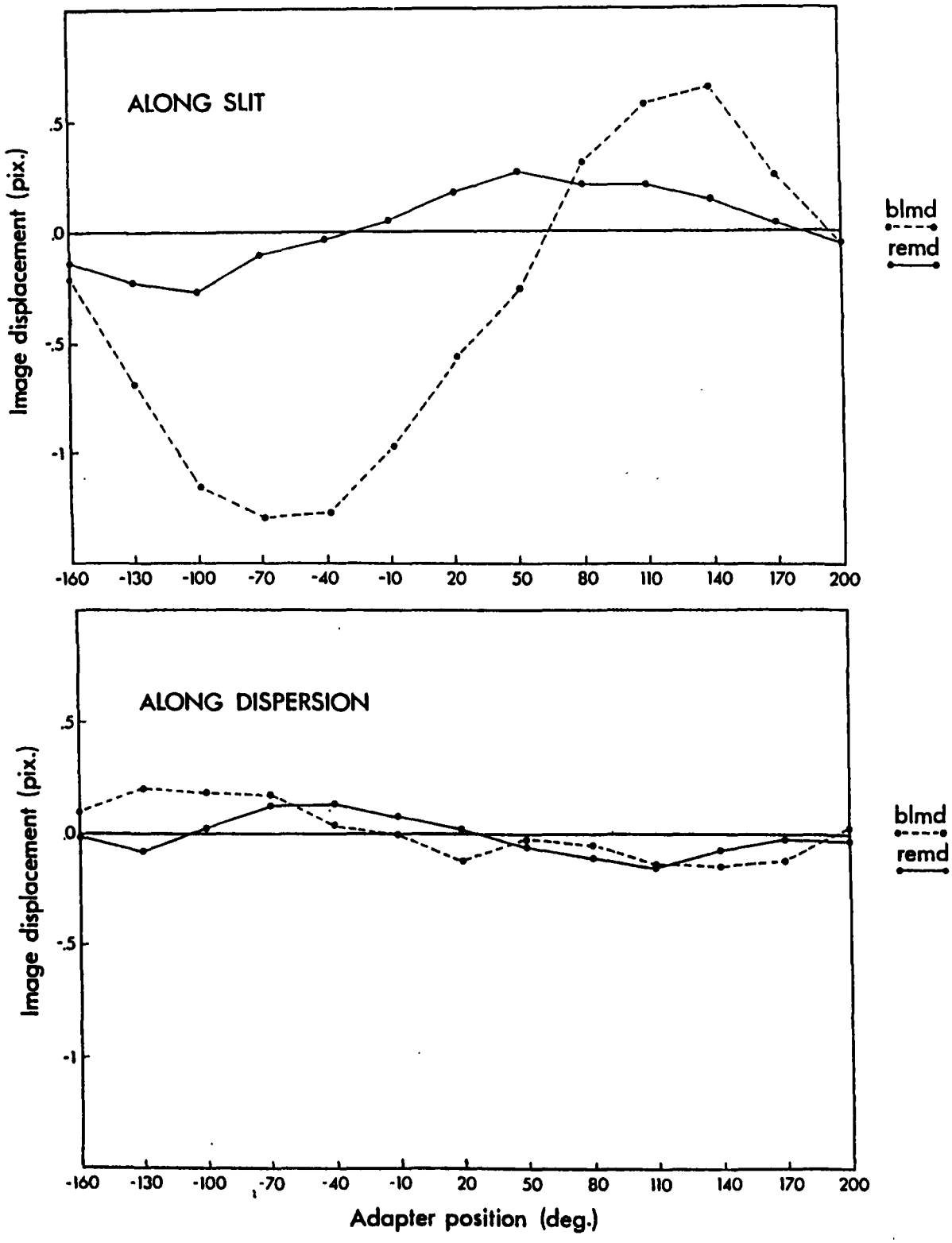

Figure 5.4: *Flexure along the slit and in the dispersion direction in grating spectroscopy (REMD or BLMD). One pixel is 19 μm.*

Along the slit, these values are 0.6 and 1.9 pixels, respectively. Critical wavelength calibration exposures should be taken at the (average) adaptor angle of the science exposure. The blue and red grating units position the gratings with a reproducibility of better than 0.1 pixel in the dispersion direction, so it is possible to gain observing time and perform your calibrations in the morning after the observing.

The flexure in the dispersion direction with grism spectroscopy in mode RILD is less than 0.2 pixel for any rotation. (Grisms are quite insensitive to flexure effects).

The image stability in the imaging modes depends not only on EMMI but also on possible flexure in the adaptor and on the guiding accuracy. This application is less critical due to the shorter exposure times and we did not observe any flexure during our tests. For < 30 minutes exposures the image position stability is better than .2 pixel.

The image position reproducibility after an initialization of the camera focus (where the camera is moved to both end stops) is better than .05 pixel. The straightness of the focus roller bearings was measured by looking at the position of an image at various focus positions. If the focus was changed by 50 encoder steps, the image moved no more than 0.2 pixels.

5.5 Instrumental polarization in EMMI and SUSI

A systematic investigation of the polarization induced by mirror 3 in the NTT and the mode-selecting mirrors in EMMI and SUSI has not been carried out yet.

Table 5.1: *Instrumental polarization of EMMI*

PA slit	Flux (e^-/s/pix at 7000 Å)
135	29.7 ± 0.2
180	30.0 ± 0.2
225	30.2 ± 0.2
270	30.4 ± 0.2

A single measurement was obtained in the following way: a standard star (FEI 110) was observed with 9″ slit and grating #6, centered around 7000Å. The exposure time was 300sec; the different exposures were taken at different P.A. of the rotator. The efficiency of this grating at 7000Å in the two polarizations is 45% and 83% respectively. If the 3rd mirror of the NTT introduces significant polarization, the efficiency is expected to change with rotator angle. The measurements gave the values shown in Table 5.1.

These preliminary measurements, therefore, indicate that the polarization induced by the NTT and EMMI may not be a worry for spectrophotometry.

5.6 The EMMI CCDs

The characteristics of the EMMI CCDs are given in the ESO CCD manual, and a summary of the relevant parameters, plus the efficiency curves may be extracted from the MIDAS context FILTERS. At the time of writing, the CCDs used with EMMI and SUSI are: CCD#18 (EMMI-red), CCD#31 (EMMI-blue), and CCD#25 (SUSI). Notice that these numbers may change due to operational problems or as new and better CCDs become available.

5.6.1 Pick-up noise

It has proven to be extremely difficult to isolate the CCD electronics from electrical interference from components in the NTT adaptors/derotators. Therefore to some extent, the EMMI and SUSI CCDs show pick-up patterns in the electronic background (the bias). This noise is minimized in SLOW readout mode, but may be rather strong in FAST readout frames. The patterns are not stable, but change from one exposure to the next, so it is difficult to remove them completely taking bias frames. However, some reduction can be achieved and, therefore, it is recommended to take a good number of bias frames throughout the observing run. Should strong patterns (i.e. more than a few ADUs) appear on SLOW readout bias frames, call Operations.

At present, pick-up noise contamination is more severe with TEK CCDs, which also have higher readout noise. The cause of this continues to be investigated.

5.6.2 Interference fringes

The Thomson THX31156 1024 CCDs show a characteristic radial fringe pattern which is due to the non–uniform coating on their surface. The amplitude of the fringes is less than 5%. The pattern is more evident in observations with narrow filters in the red or with broad filters which include strong sky emission lines in their transmission bands.

The fringing can be corrected with the proper flatfield exposures. In imaging, this is done with sky exposures from which the stars have been removed. Reduction of test data have shown that the fringing correction with this technique can be as good as 10% of the sky intensity.

On spectroscopic observations, flatfields obtained with the standard lamps can be used for fringing corrections. Reduction of grating spectra in the far red using available MIDAS routines have shown that the sky lines can be efficiently subtracted to at least 5% of their intensity.

5.6.3 Saturation and remanence

A few notes of caution are in order regarding the use of the Thomson THX1024 CCDs. The physical saturation level is close to 160,000 e^-, and the CCD is linear up to about 50,000 e^-. For slow readout speed this corresponds to about 25,000 ADUs, well within the 15-bit numerical precision of IHAP. Notice that for exposures above half the physical saturation level there is significant remanence on the CCDs. For saturated exposures (160,000 electrons) a remanence of about 50 e^- is left for about 10 minutes. Heavier saturation leads to remanence lasting several hours. Therefore **avoid** heavy saturation as much as possible, but if saturation in unavoidable, remember that it may take up to a few hours before the effect disappears completely.

At the red arm of EMMI saturation is a severe problem because, with its large field, it is often difficult to avoid bright stars. It is planned to replace the THX1024 CCD by a TEK2048 chip mounted on the available F/5.3 camera during 1993. Because the delivery date of the TEK2048 CCD is uncertain, it is also planned to install a coated FA2048 chip at the beginning of 1993.

Until this is done, it is important to avoid heavy saturation of the CCD. Should for some reason heavy saturation occur, it may take hours or even days to dissapear, but an alternative solution is to warm the CCD and then cool it again. This procedure, however, requires at least one full day. Some special round masks are available, and others can be made, that limit the field of view of RILD to allow observing objects near very bright stars. The data tabulated in Table 3.6 can be used to determine how bright a nearby star can be as a function of your exposure time.

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Appendix A

EMMI Observing Batches

There are several batch programs (procedures) in IHAP and MIDAS that are needed for observing with EMMI. The images from the two EMMI CCDs and from SUSI are automatically and simultaneously transmitted to both the IHAP and MIDAS computers. The observing batches in both systems do essentially the same job, and therefore the observer can choose the system he/she is most familiar with. Notice, however, that the program to prepare MOS masks is only supported in MIDAS.

To log–on in the IHAP station give the username `EMMIHAP` (no password) and use the first softkey (F1) to enter in IHAP. 100 Mby of disk space (the maximum allowed by IHAP) are available for data storage. In practice this means that only about 25 full format 1024^2 CCD images can be stored in the IHAP database. The commands `PURGE` and `PACK` must be used to make space for new images. Be sure that your data is stored on tape before using these commands.

To log–on in the SUN/MIDAS workstation the username is `CCD` and the password is `lasilla`. The MIDAS implementation at the NTT uses two monitors, a normal one (right), and one exclusively dedicated to image display (left). After log–on a number of X11 windows appear on the right–hand screen. The light blue window at the upper right is the data transfer log window. The remainder are standard X11 windows. MIDAS is automatically started in the white window. Images arrive from the EMMI and SUSI CCDs in FITS format (.mt) and are automatically converted to BDF format and displayed in the large display window (left monitor). Approximately 1 Gby of disk storage is available for MIDAS. A small Graphical User Interface appears on top of the display window showing the MIDAS observing batches. These can be executed by positioning the mouse cursor on top of the corresponding field, and clicking the left button. Some of these fields are pulldown menus offering several options. For example, if you click `Focus` you get two options: `sequence` and `wedge`, for measuring focus sequences and exposures with the focus wedge respectively. If you select the `sequence` option, a pop-up window will appear where you will be requested to give the parameters of the focus sequence (start, step). Other batches (e.g. `POINT`) also prompt in the same way for pointing parameters. The blue key provides some utilities. The use of this graphical interface is straightforward.

Internally, the graphical interface works by simply composing the corresponding MIDAS commands and sending them to the MIDAS window. Therefore, it is also possible to give the commands by typing them on that window. The MIDAS observing procedures invoked are essentially identical to the corresponding IHAP batches and are briefly described below.

A.1 IHAP batches

A number of IHAP batches are available to the observers. The list of batches with a brief description of their use is given below. In most cases, the batches have been adapted from EFOSC. The batch programs have a help facility that may be called with the command: `BATCH,xxxxx,,HELP`

EMPOINT

Description: Point offsetting from direct image.
Syntax: `BATCH,EMPOINT,,XSLT,YSLT,[size],[ang],[MED]`
Parameters:

XSLT, YSLT	=	position of the slit. RILD slit is oriented NS.
size	=	(optional) size of centreing box. Default = 15 pix.
ang	=	(optional) rotator OFFSET.
MED	=	(optional) give MED for medium dispersion (EW) slit.

EMSLIT

Description: Draw slit position.
Syntax: `BATCH,EMSLIT,,[#],XSLT,YSLT,[MED]`
Parameters:

#	=	(optional) file number. Default: G10.
XSLT,YSLT	=	slit position.
MED	=	(optional) set to MED for REMD/BLMD slit (EW). Default: RILD slit (NS).

EMROTA

Description: Determine angle between two objects.
Syntax: `BATCH,EMROTA,,[CURSOR]`
Parameters: CURSOR = (optional) Use cursor position instead of Gaussian fits.

EMFOCUS

Description: Focus using focus wedge; RILD mode only.
Syntax: `BATCH,EMFOCUS,,[#]`
Parameters: # = file number. Default G10.
Note: *Focus for RILD and REMD modes are the same*

EBSEE (BIMG), **ERSEE** (RILD), **SUSEE** (SUSI)
Description: Determine seeing.
Syntax: `BATCH,ERSEE,,[#]`; `BATCH,EBSEE,,[#]`; `BATCH,SUSEE,,[#]`

KDISPC
Description: Determine cuts automatically.
Syntax: `BATCH,KDISPC,,[#]`

TFOCUS
Description: Focus of telescope using through–focus sequences.
Syntax: `BATCH,TFOCUS,,[#],[start],[step],[box]`

Parameters:	#	=	(optional) File number. Default: G10.
	start	=	(optional) Stating focus value. Default: 0.0.
	step	=	(optional) Focus step. Default: 1.0.
	box	=	(optional) Centreing box size. Default: 20 pixels.

A.2 MIDAS procedures

As described above, the MIDAS observing batches may be run by clicking the corresponding button on the graphical X11 user interface that appears on top of the MIDAS display window. Below we give a description of the procedures invoked by these buttons. The corresponding button is also indicated.

`@@ loadn image [-n ]` Equivalent to KDISPC. The optional parameter (n) is the scaling factor as in the MIDAS command `load`.

focus: This is a pull-dwon menu with 2 options:
focus wedge (`@@ focus`) which is equivalent to EMFOCUS, and
focus sequence (`@@ tfocus [start] [step]`) that is equivalent to TFOCUS.

seeing: (`@@ seeing`) . Equivalent to ERSEE (RILD), EBSEE (BIMG), and SUSEE (SUSI). In MIDAS the procedure automatically determines the appropriate pixel scaling, and therefore the same procedure can be used for the three image types.

point: (`@@ point [xslit] [yslit] [angle] [flag]`) . Equivalent to EMPOINT. The procedure prompts for the parameters if not given. The angle is defaulted to 0. If the flag is set to `C` the cursor is used to define the position instead of Gaussian fits (default).

rotate: (`@@ rotate`) . Equivalent to EMROTA. This is a pull-down menu with two options for gauss, and cursor centreing of the objects. Notice that `rotate` assumes that the slit is oriented NS.

trace: This calls the MIDAS command `extract/trace`. The trace is extracted between a fiducial point and the position of the mouse cursor. Use the arrows to change the fiducial mark. The keyboard keys 1-9 may be used to speed up this motion.

catalog: This pull-down menu has options to list the headers of the RED, BLUE, and SUSI files in the MIDAS window, and to reset the catalogues. Once the catalogues are reset, they must be created again with the `create/icat` command. This is automatically done at the beginning of the session.

utils: This pull-down menu contains options to get the cursor and to print the graphics windows on the laser printer.

A.3 Making MOS plates

The MIDAS context `EMOS` allows to prepare interactively the ASCII tables used by EMMI to punch MOS aperture plates. `EMOS` uses a mouse driven X11 graphical interface and can be run at any MIDAS installation equipped with X11. This interface consists of three elements: a parameters window, a dialog window, and a set of buttons and pull-down menus. These buttons are "pushed" by clicking the left mouse button at the corresponding position. Like other MIDAS X11 contexts, `EMOS` has an on-line help facility which works by clicking the *right* mouse button in any key. A window with a brief description of the function appears on the terminal for as long as the mouse button is pressed.

To start the interface type: `create/gui emos` . The Graphical User Interface (GUI) window will appear on the upper right corner of the screen. A sample of the main EMOS window is shown in Table A.1. The fields demarked by dotted lines in the parameters area display information read from the file headers. The other fields are used to input parameters to the program as follows:

Slit length (pixels): The length value to be used for punching **center slits**. This value may be changed at any time during the preparation of the masks, so centered slits of different lenghts may be easily punched. This value also specifies the minimum slit lengh for the **automatic** mode. The shortest slit that can be punched is 8.6 arcseconds.

Min dist from edge (pixels): Specifies the minimum distance allowed for an object to lie from the edge of its own slit. This parameter is necessary because in the **automatic** mode EMOS optimizes the lenghts and centering of the slits to fit the maximum number of objects in one mask.

Min interslit gap (pixels): Sets the minimum separation allowed between contiguous slits.

Box size (pixels): Size of the box used for centering objects (MIDAS command `center/gauss`).

Inventory zero magnitude: Zero point of the magnitude scale (for 1 sec integration). This value is used in the automatic search mode for selecting the magnitude range of the galaxies to be chosen. If the zero point is not given, the programme uses instrumental magnitudes as determined by `INVENTORY`.

Inventory threshold (ADU): Defines the threshold used by `INVENTORY` for automatically finding objects (used only in the `automatic` mode).

To change any of these parameters, simply move the cursor to the corresponding field and type the new value. It will be sent to MIDAS as soon as the cursor is moved out of the field. Check in the MIDAS window that this happens.

Table A.1: *Main window of EMOS.*

Current image	mira0002.bdf
CCD name	THX31156
CCD number & size (x,y)	#18 1100,1040
Window (x1,y1,xN,yN,stepx,stepy)	1,1,1101,1041,1,1
Pixel size (microns)	19
Slit length (pixels)	30
Min dist from slit edge (pixels)	5
Min interslit gap (pixels)	5
Box size (pixels)	10
Inventory zero magnitude	0.00
Inventory threshold (ADU)	30

automatic	*histogram*	*next mask*	fixed slits	center slits	delete slit
displ mask	show range	*send mask*	overlay	utils	return

The main EMOS menu has three options: **load** to load an image and read the descriptors, **MOS** that leads to another menu for preparing the mask, and **Utils** which is a pulldown menu containing a number of MIDAS utilities commands (e.g. `create/display`, `create/graphics`, etc.). After you click **load** the list of MIDAS `.bdf` files in your working directory appears in a pop-up window. Click the name of the file you wish to load. Then go to **MOS**. A new set of buttons appears in the GUI with the configuration shown in Table A.1.

automatic. This pull-down menu has two options: **stars** and **galaxies**. EMOS prompts for a sub-image, which must be specified giving the lower-left and upper-right corners with the graphics cursor, and calls `INVENTORY` to search for objects in the sub-image brighter than the threshold value defined in the parameters field. `INVENTORY` determines the centroid and the magnitude of each object, and does a star/galaxy separation, plotting a yellow circle on top of all the stars or galaxies found. The histogram of magnitudes is displayed and, using the cursor, you must specify the magnitude range of the objects (stars or galaxies) to be used for the mask. The button **histogram** is enabled and may be used to change the magnitude range later if required. A table with all the objects selected by INVENTORY within the given magnitude range is prepared, and all objects within the specified magnitude range are plotted in red. Then a sub-set is selected such that the number of objects that fit in one mask is maximized by choosing slits-lenghts as close as possible to the minimum value specified in the parameters window. The command **next mask** can be used to iterate until all the objects in the table have been selected (see below).

histogram. A plot of the distribution of magnitudes of the objects found by INVENTORY is given, and the graphics cursor is used to select the magnitude range of the objects to be included in the list to be punched.

next mask. This command allows to punch the next objects in the list prepared in the **automatic** mode. By using this command repeatedly, all the objects within the selected magnitude range may be punched systematically in several masks.

fixed slits. This command allows slits of any length to be defined interactively. Mark the lower and upper position of the slit with the graphics cursor using the left button of the mouse. The first time the X position of the slit and the lower Y edge are defined. Click again to define the upper Y edge of the slit. The X position of the cursor is ignored the second time.

centered slits. Center the box on an object and click the left mouse button. The X,Y position is defined by a Gaussian fit (`center/gauss`). The length of the slits is defined in the parameter definition window as described above. **centered slits** and **fixed slits** may be used both to create a new mask or to modify an existing one.

`delete slit`. Click at the position of a slit (within 15 pixels) to delete it.

`displ mask`. This pull-down menu allows to plot the current mask top of the displayed image (`show current mask`), to load a different mask from the disk (`load new mask`), or to erase the current mask to start a new one (`reset mask`). In order to avoid erasing the current mask accidentaly, the last two options request confirmation. The `overlay` pull-down menu may be used to choose the colour in which the masks will be displayed.

`show range`. This command is used in 2 steps: the first time on the list of the 6 EMMI grisms with the maximum possible wavelength range appears on the MIDAS window, and a new parameters window appears in the GUI. You must enter the grism number, and the required wavelength range. `show range` is then used again to delineate the area where the specified range may be realized and to show the region which can be reached mechanically by the punching engine. Remember that using grisms the wavelength range depends on the position of the slit (c.f. Table 3.5).

`send mask`. After the mask has been prepared, this command sends the final ASCII table to the NTI computer to be used by EMMI. The name of the file is given. It is composed of the name of the direct image used to prepare the mask plus a number. This command also allows to store the current mask on disk. The same name is used.

`overlay`. Allows selecting the colour of the line graphics on the image display. This command is particularly useful to modify masks. An option to clear the overlay plane is also provided in this menu.

`utils`. This pulldown menu contains a number of useful utilities.

`return`. Return to main menu.

Appendix B

EMMI Efficiencies

The efficiencies of the individual EMMI optical components are given below. The efficiency curves for the echelle gratings are not shown, but overall efficiencies of the echelle mode are given in Chapter 2 of this manual. The grating and grism curves do not include the efficiencies of the EMMI optics and the CCDs which are shown separately. Curves showing the convolved efficiencies are given in reference [6].

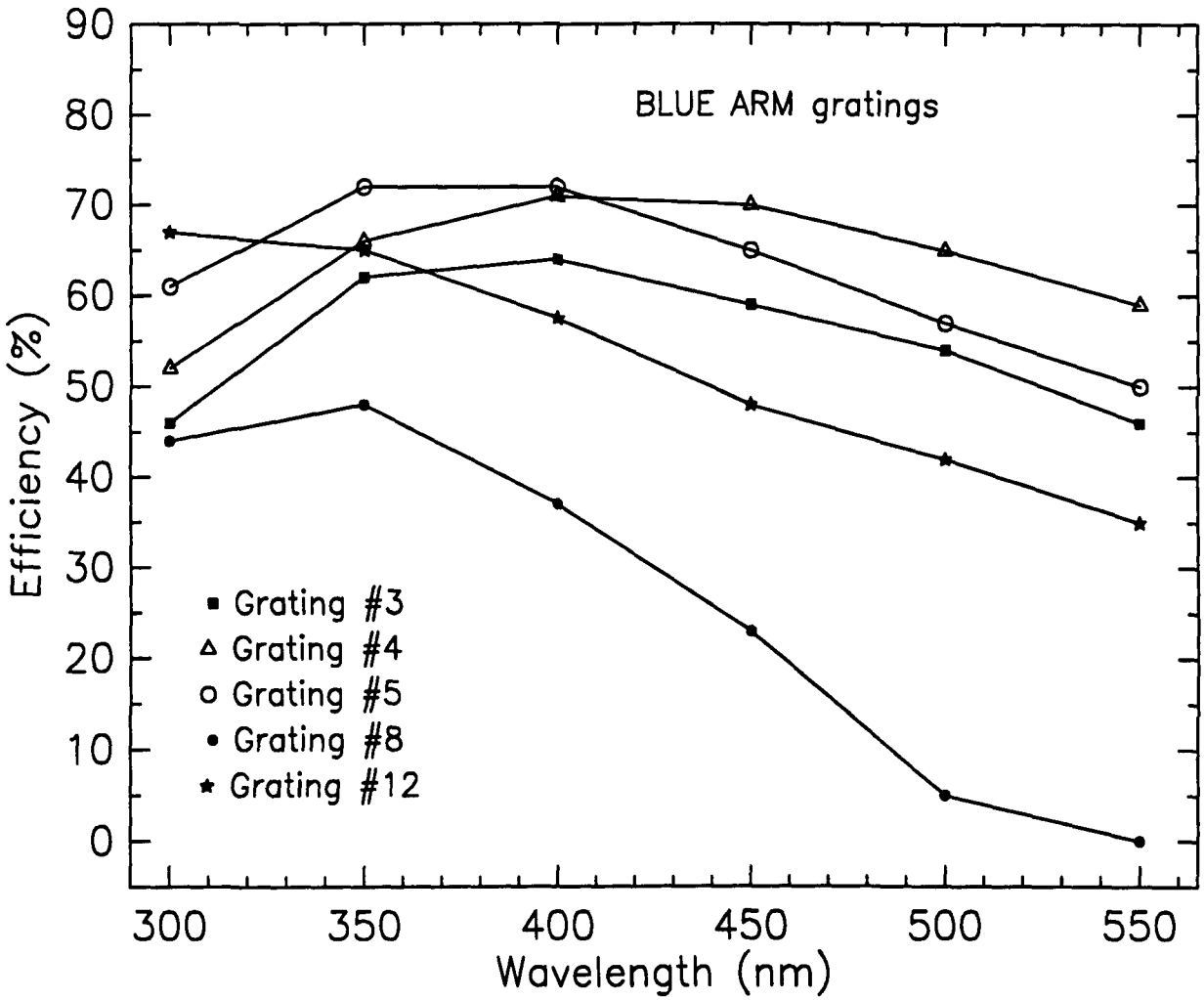


Figure B.1: *Absolute reflectivity curves for the gratings used in the blue arm of EMMI. The efficiency of the EMMI optics, the NTT mirrors, and the CCDs are not considered in these curves.*

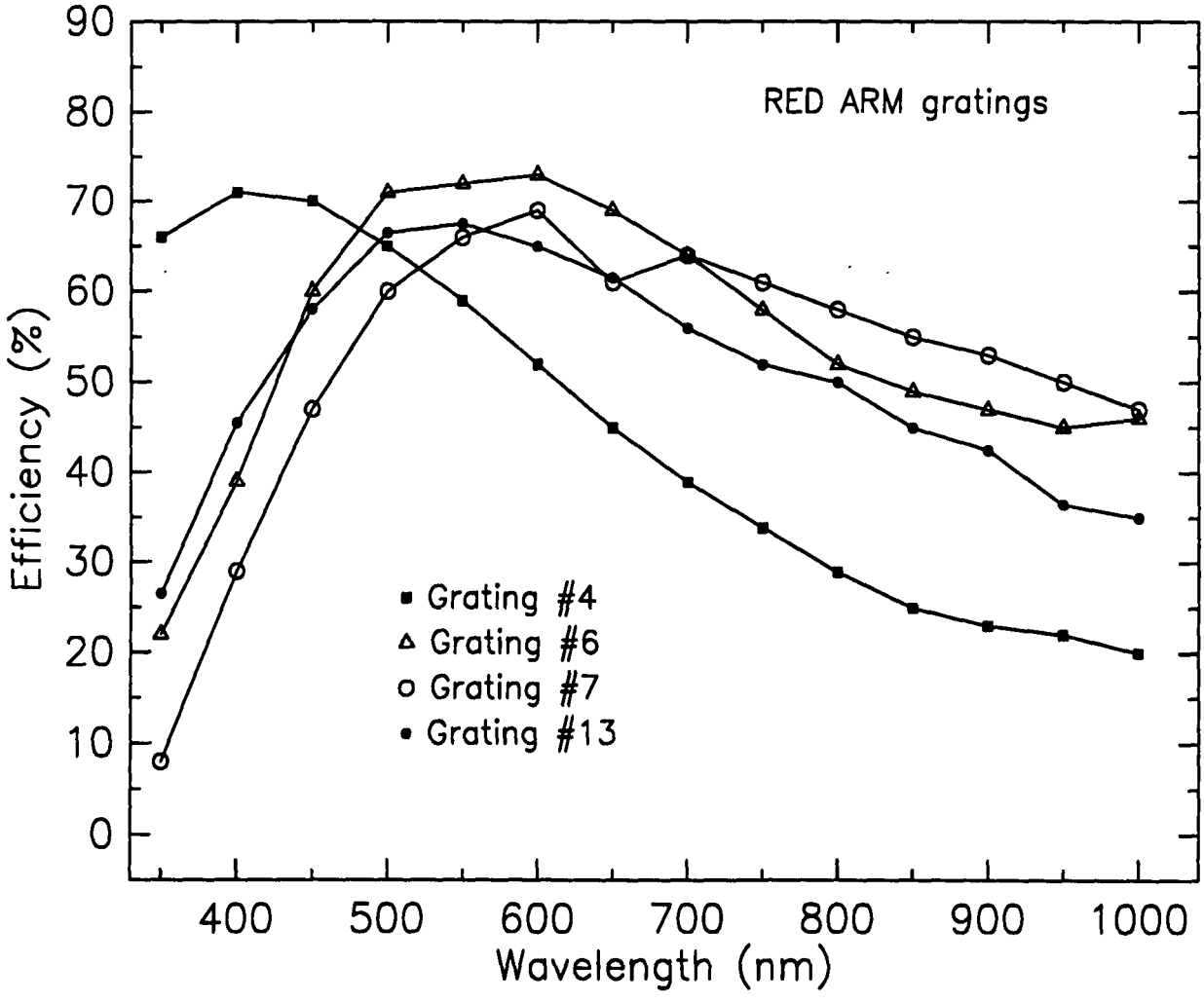


Figure B.2: *Absolute reflectivity curves for the gratings used in the red arm of EMMI. The efficiency of the EMMI optics, the NTT mirrors, and the CCDs are not considered in these curves.*

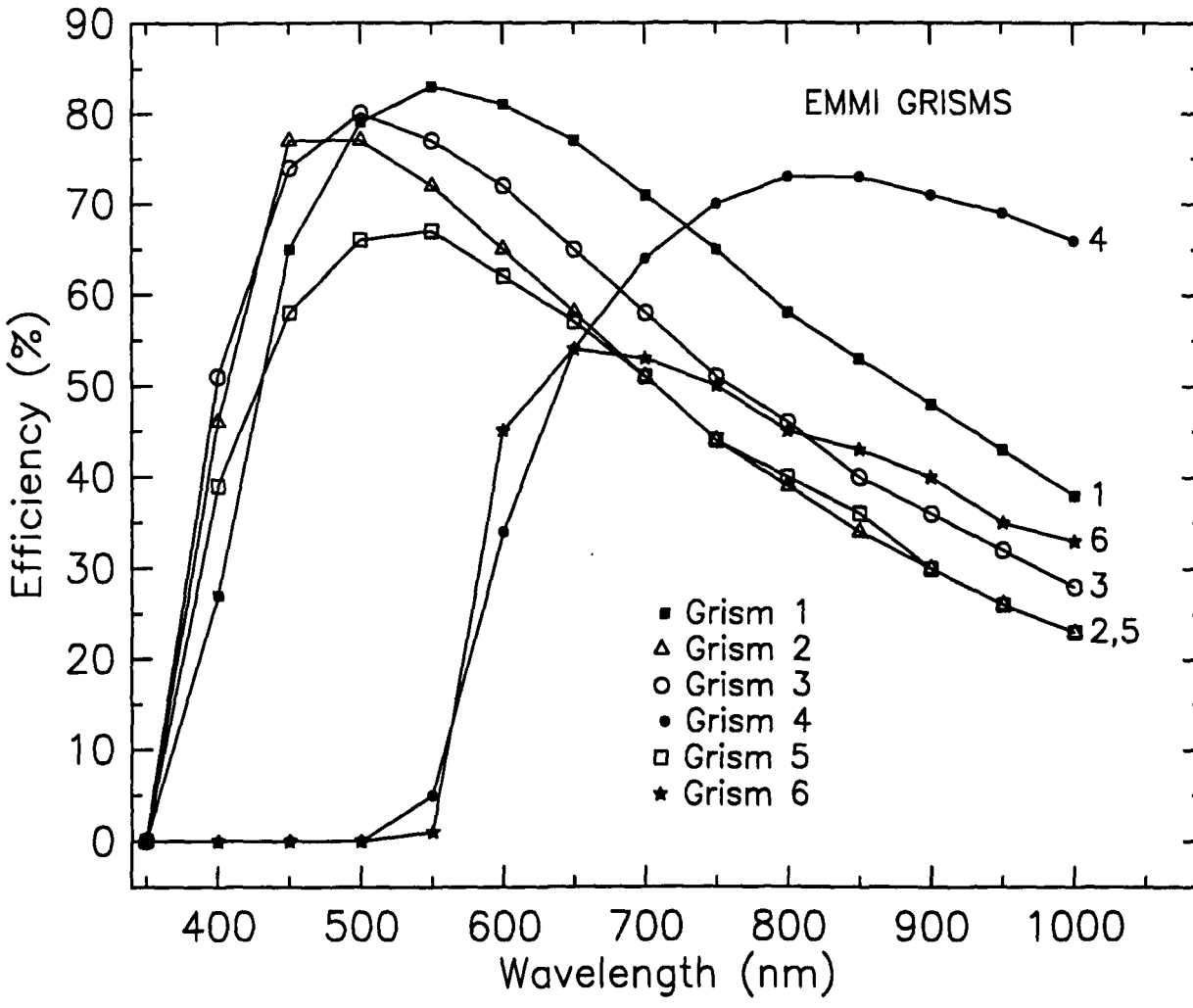


Figure B.3: *Transmission curves of the EMMI grisms. The efficiency of the EMMI optics, the NTT mirrors, and the CCDs are not considered in these curves.*

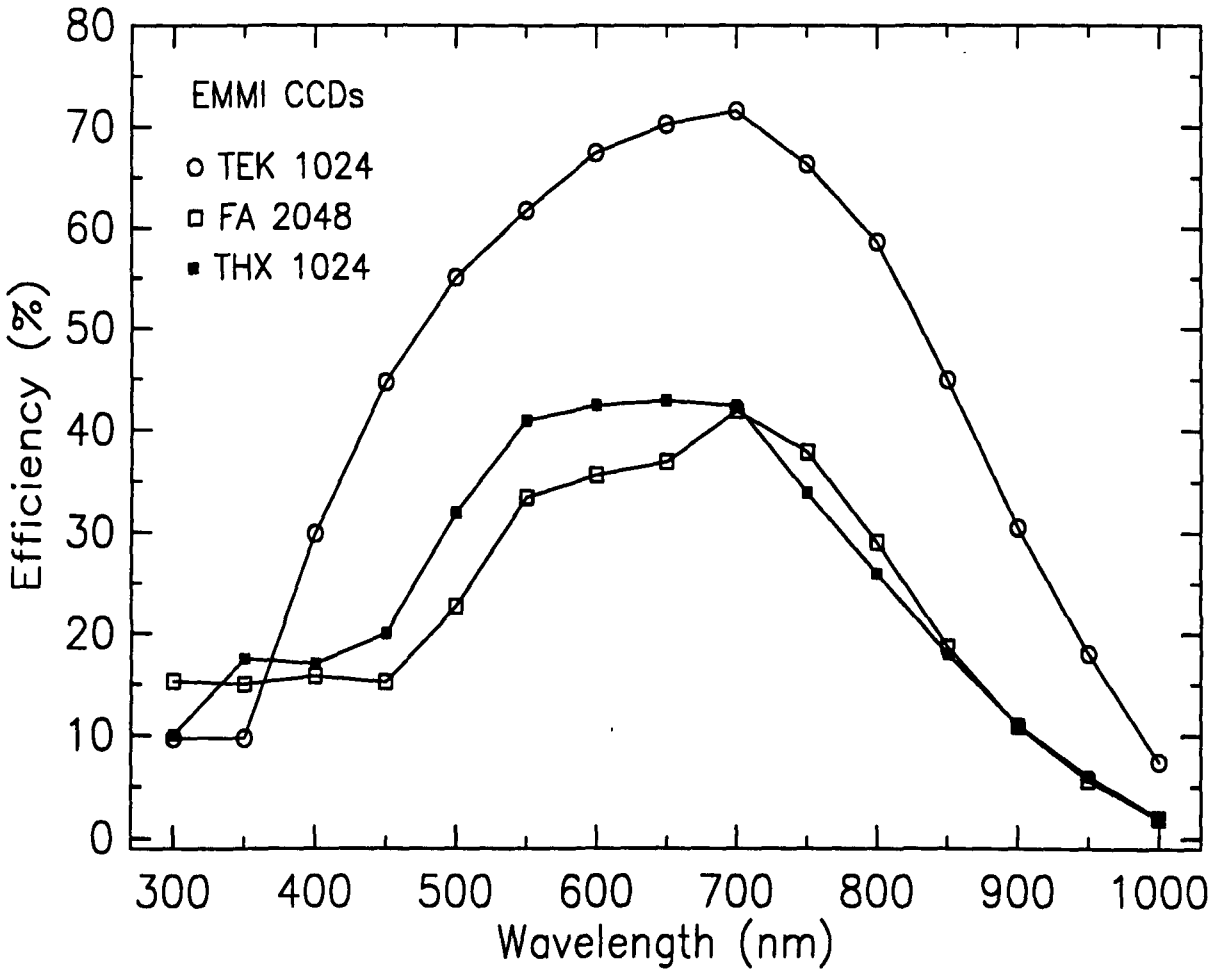


Figure B.4: *Quantum efficiencies of the EMMI CCDs.*

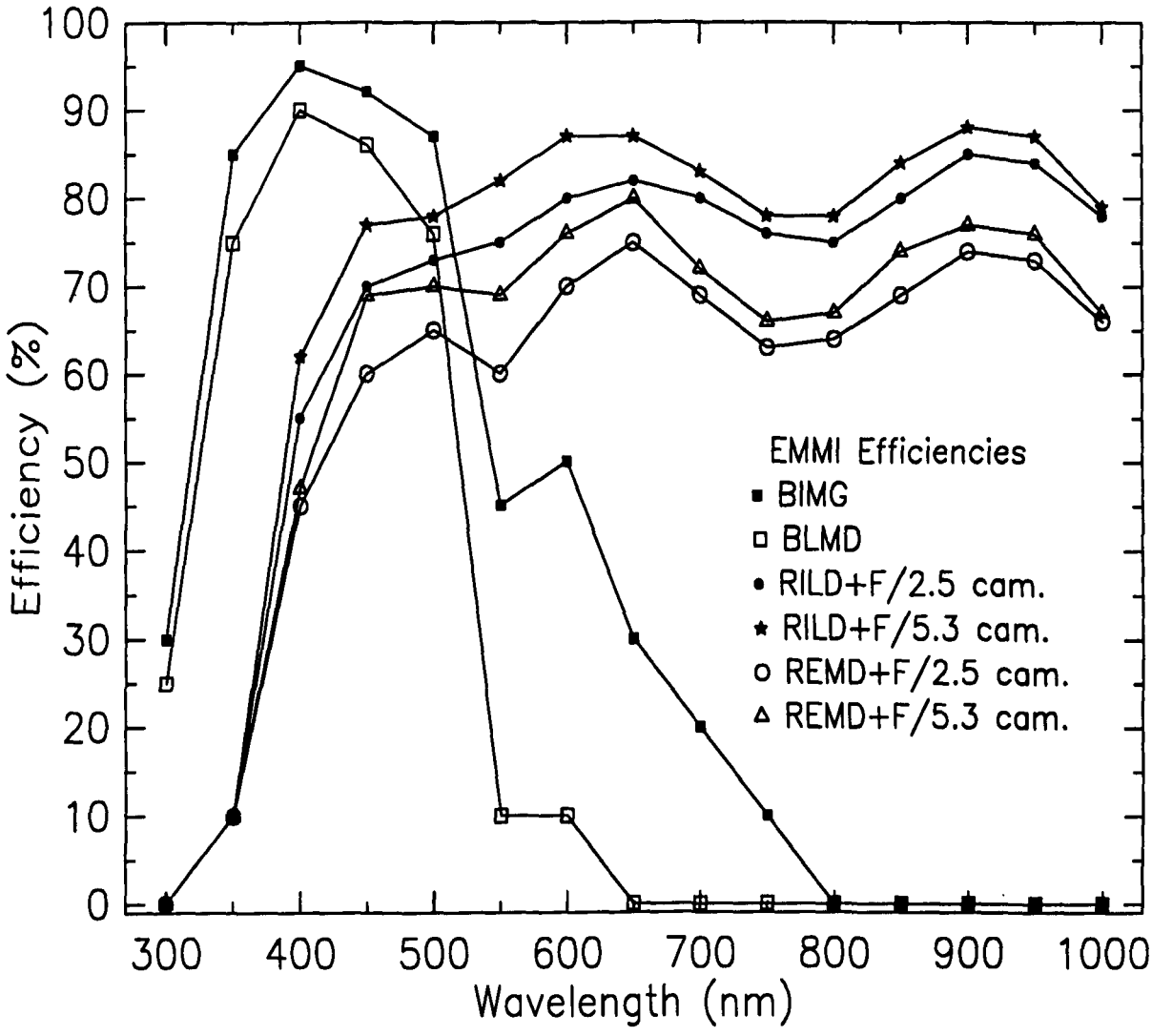
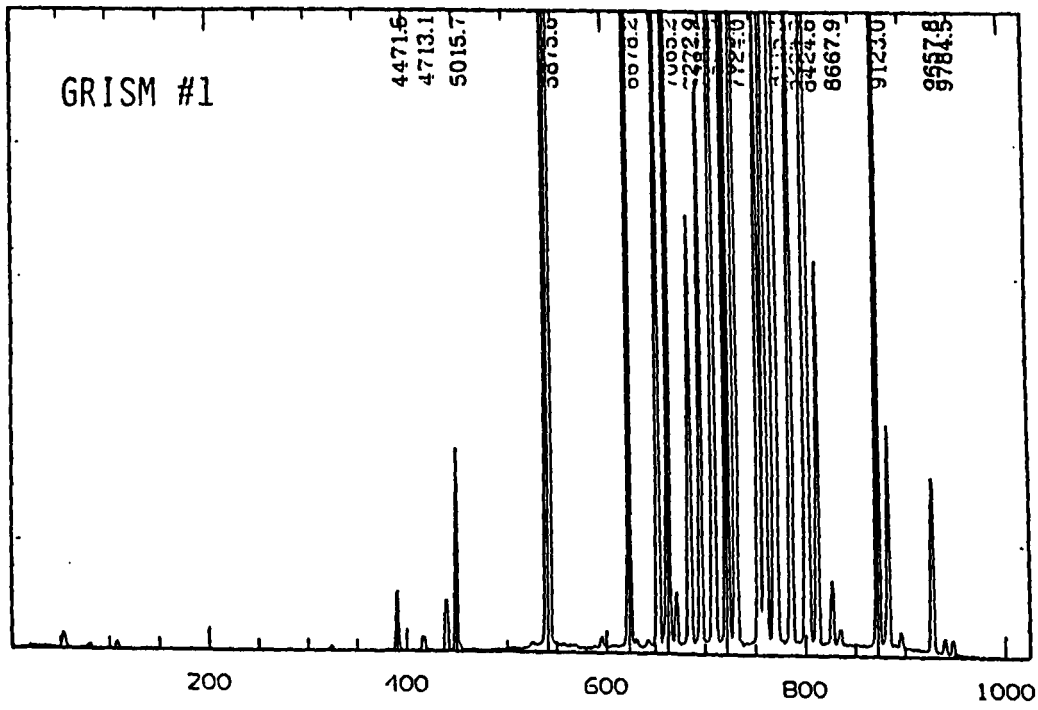


Figure B.5: *Transmission of the EMMI optics in the grism and grating spectroscopy modes.*

Appendix C

He-Ar Atlas for EMMI Grisms

Representative He-Ar spectra taken with the EMMI grisms are presented below. All spectra were obtained using a 1.5″ slit and fast readout. The exposure times are given in Table 3.5. The most prominent lines are indicated. These curves can also be used to identify the lines in grating spectra. The full He-Ar atlas tables are available both in MIDAS and IHAP for reductions.



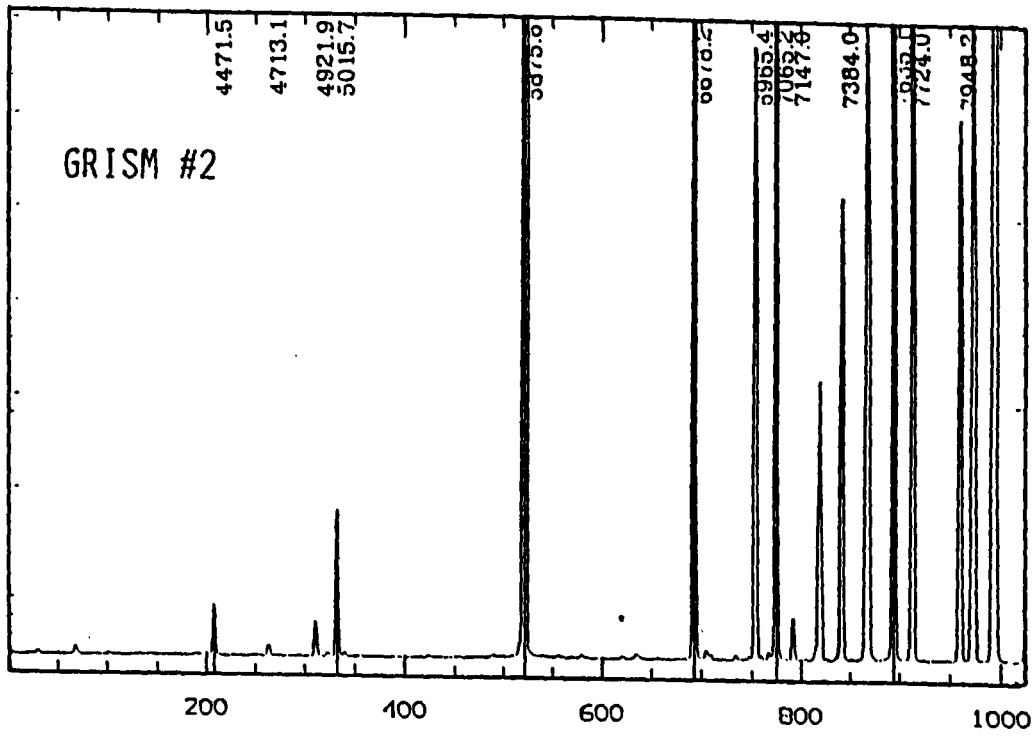


Figure C.1: *He-Ar line identifications for grisms #1 and #2.*

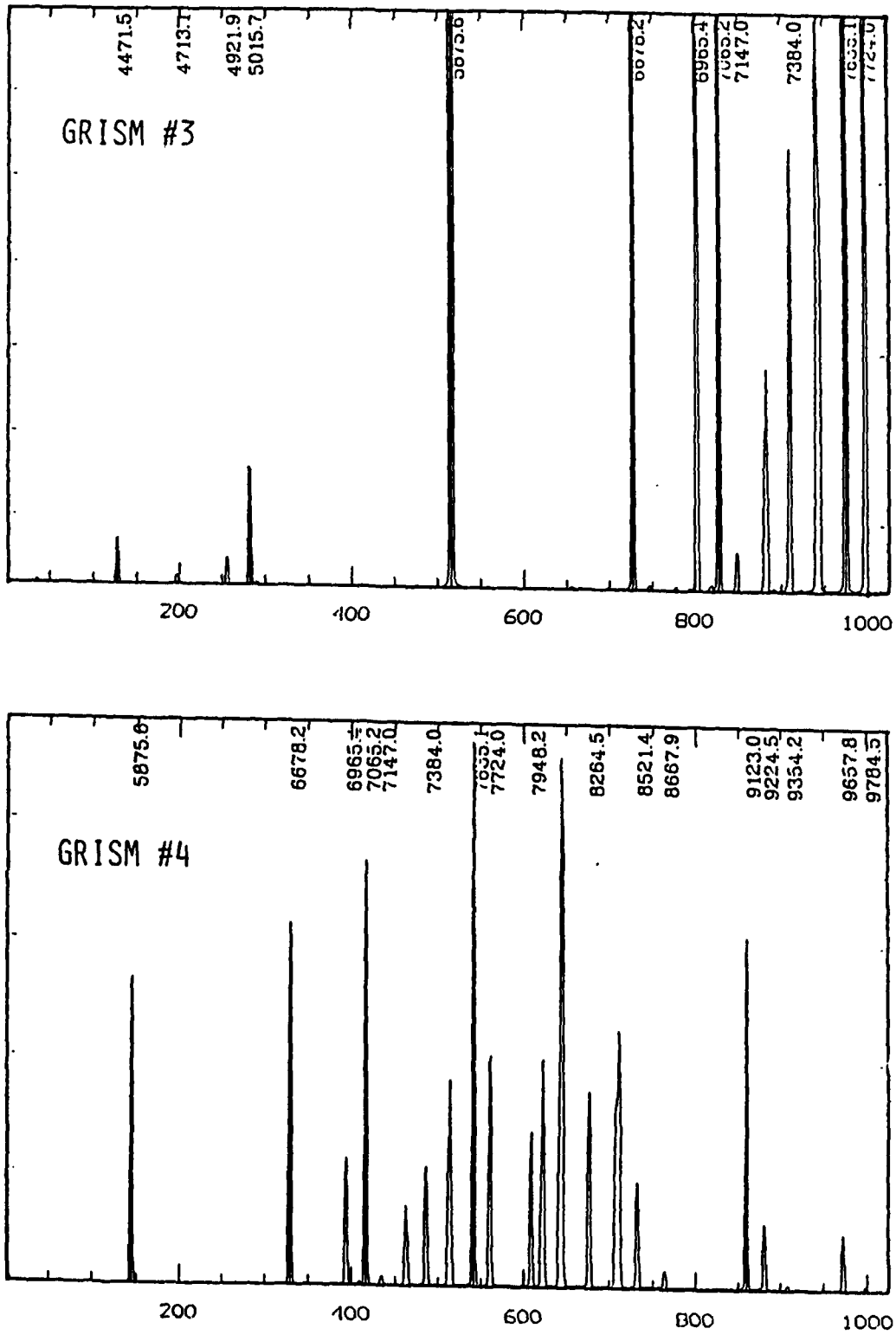


Figure C.2: *He-Ar line identifications for grisms #3 and #4.*

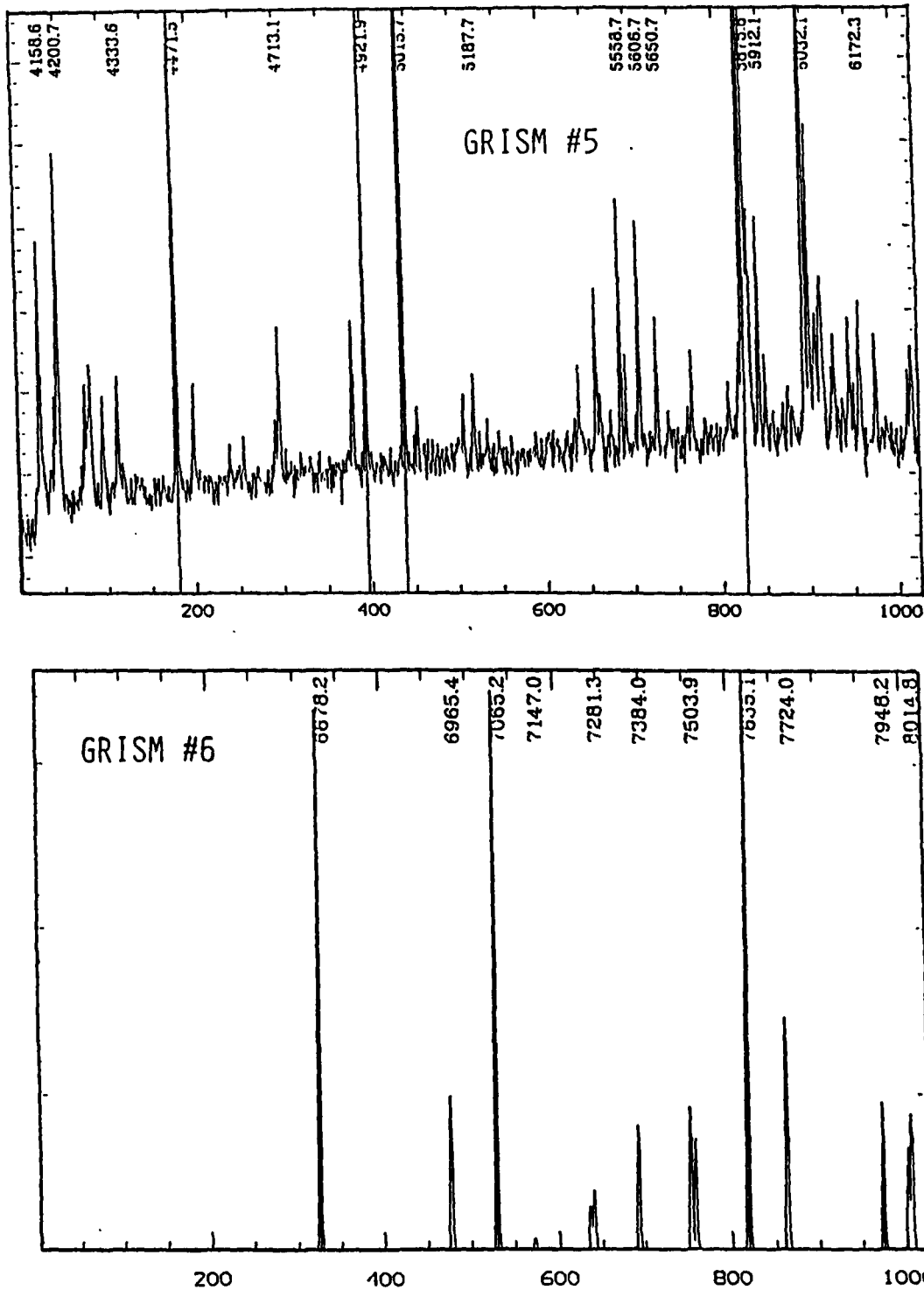


Figure C.3: ***He-Ar line identifications for grisms #5 and #6.***

Appendix D

Th-Ar Atlas for High Dispersion Gratings

Spectra of the Th-Ar lamp taken with the EMMI echelle gratings are given below. The orders are indicated. Line identifications are given in reference [1].

Th-Ar identification charts for gratings #3 and #11, for which the He-Ar lamps do not provide enough bines are also presented, centred at the blaze wavelength. Line identification for other grating angles can easily be made using the plots given in reference [1].

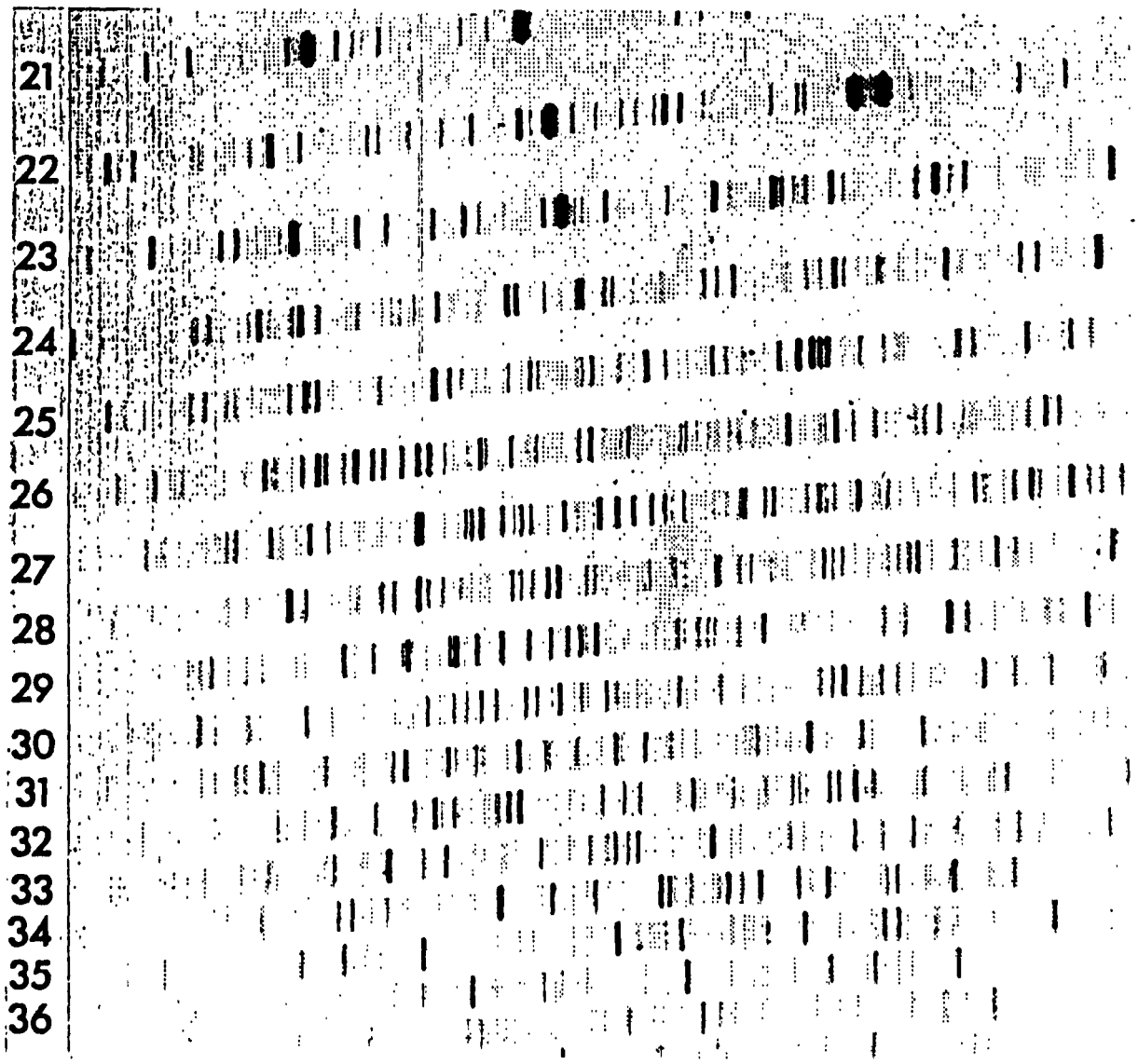


Figure D.1: *Th-Ar atlas for grating #9+grism 3 cross-disperser (10″ decker). THX 1024 CCD and F/2,5 camera.*

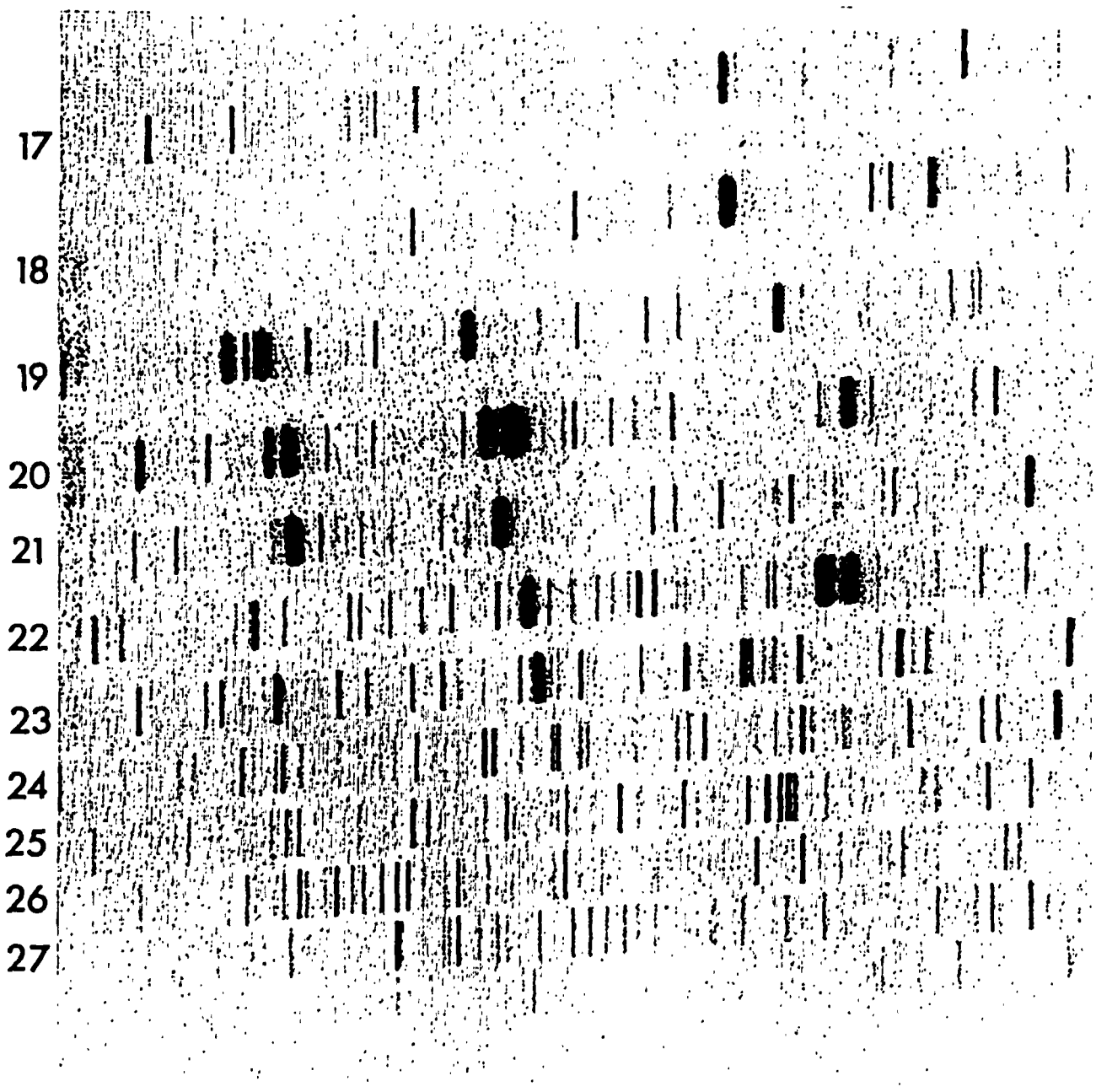


Figure D.2: *Th-Ar atlas for grating #9+grism 4 cross-disperser. THX 1024 CCD with F/2.5 camera.*

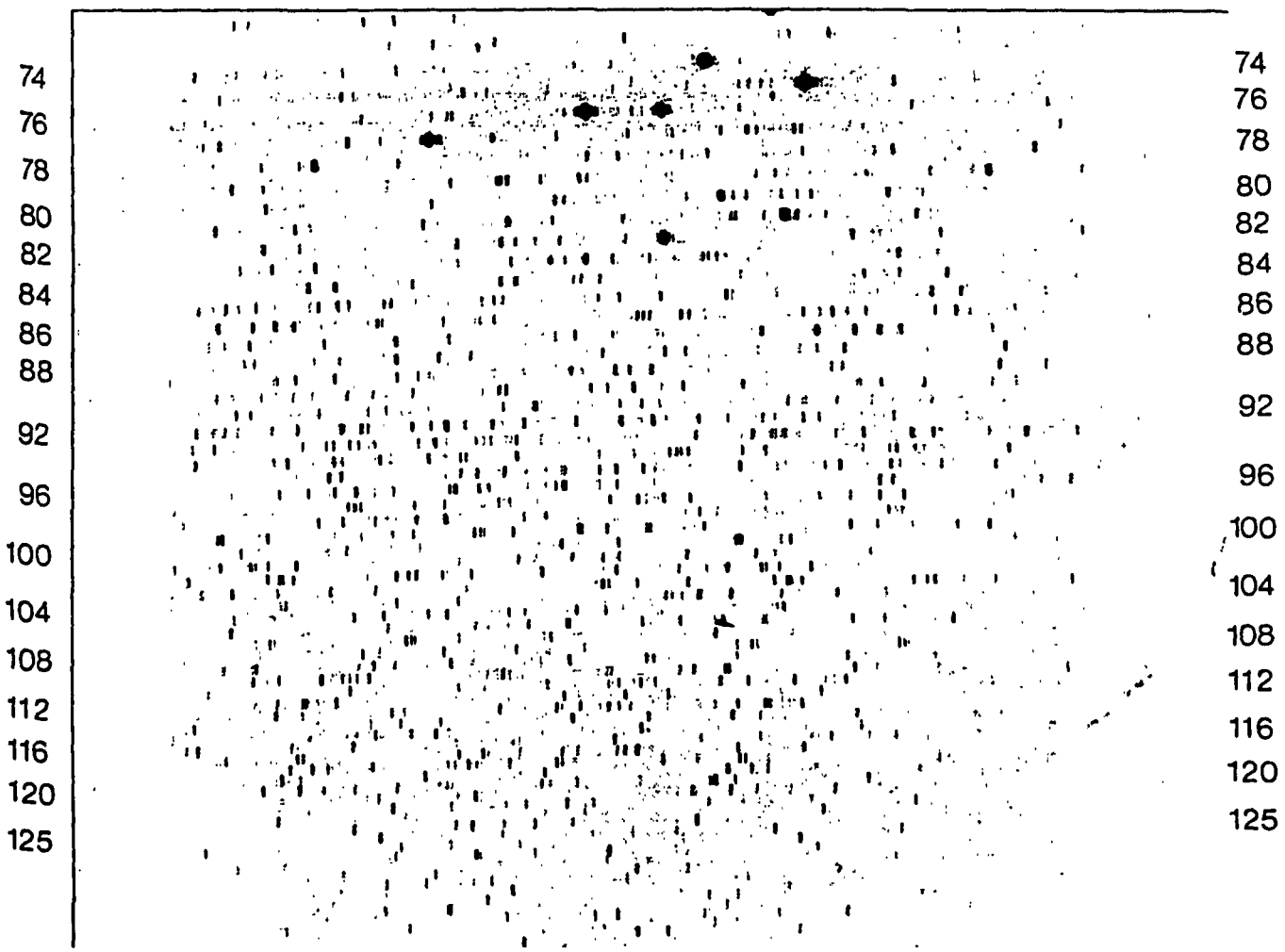


Figure D.3: *Th-Ar atlas for grating #10+grism 3 cross-disperser (10″ decker). F/2.5 camera and THX 1024 CCD.*

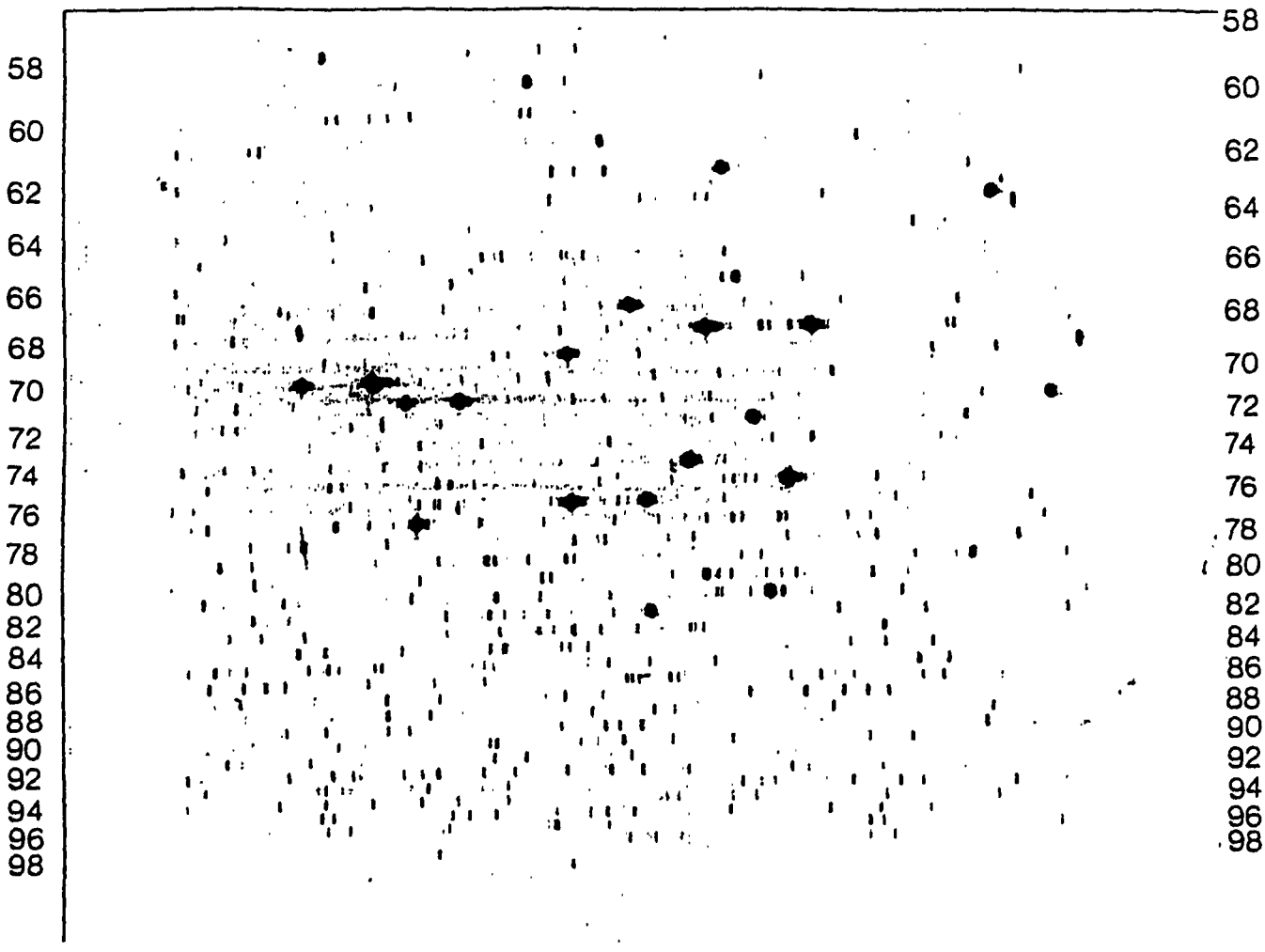


Figure D.4: *Th-Ar atlas for grating #10+grism 4 cross-disperser. THX 1024 CCD with F/2.5 camera.*

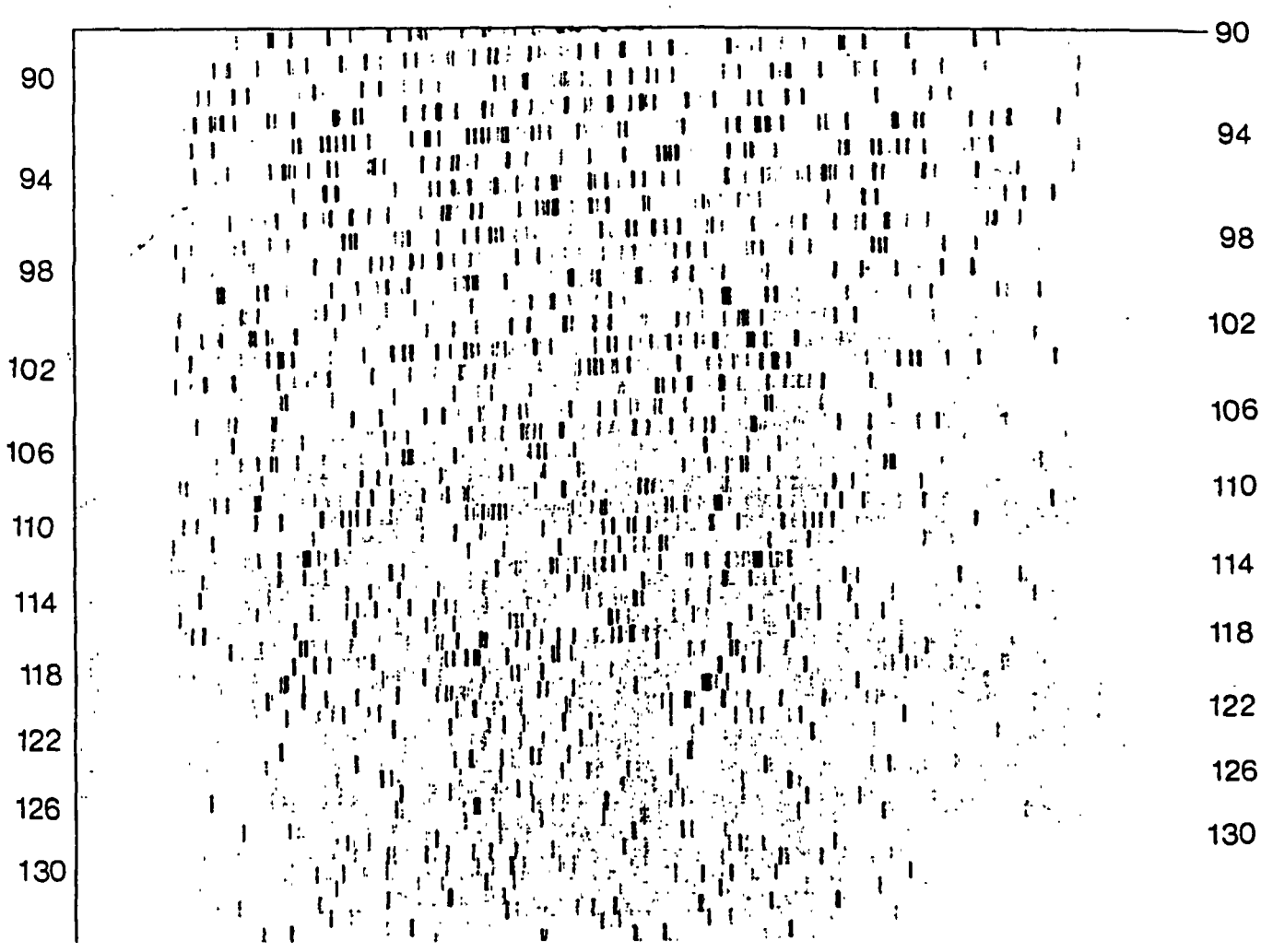


Figure D.5: *Th-Ar atlas for grating #10+grism 5 cross-disperser. THX 1024 CCD with F/2.5 camera.*

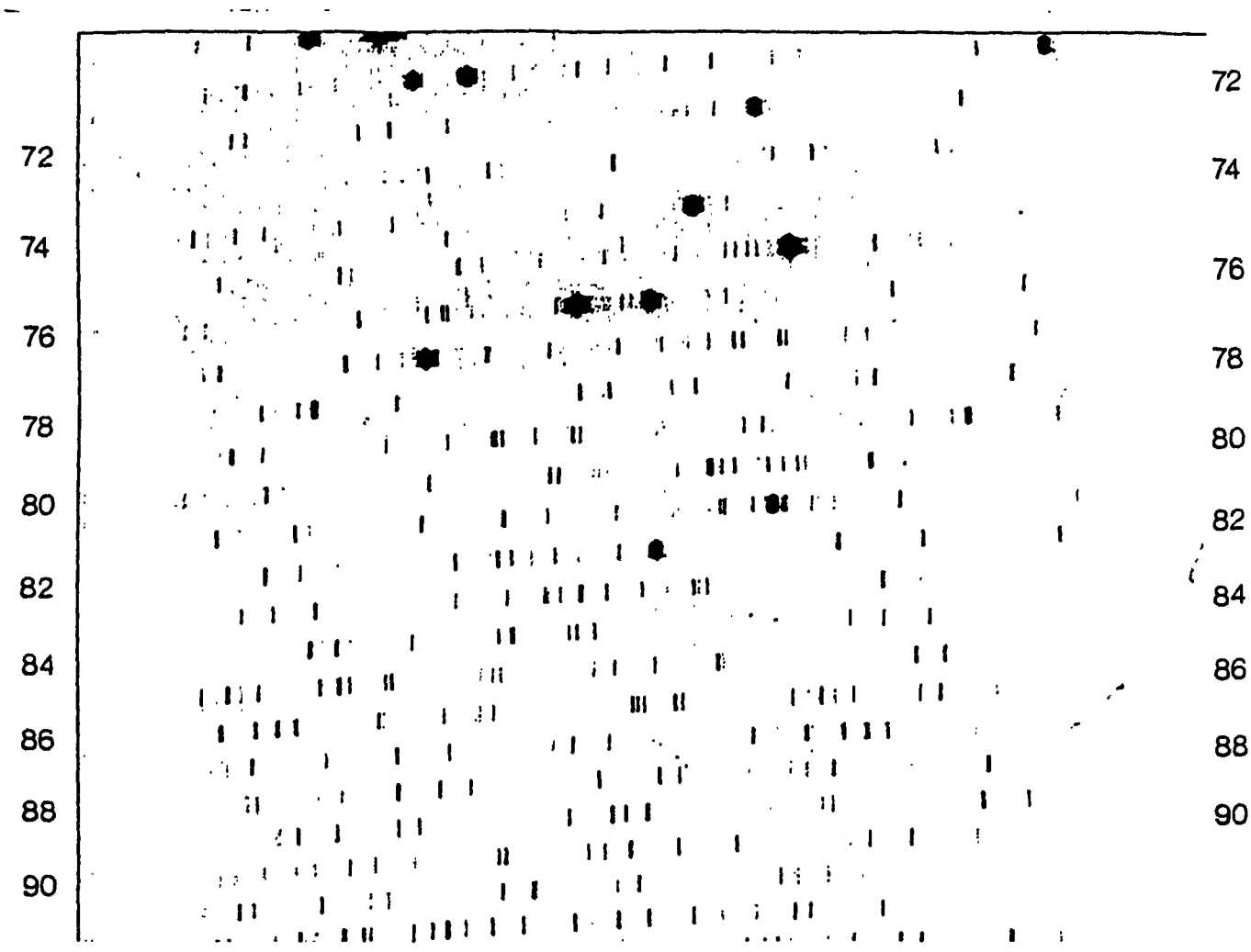


Figure D.6: *Th-Ar atlas for grating #10+grism 6 cross-disperser. THX 1024 CCD with F/2.5 camera.*

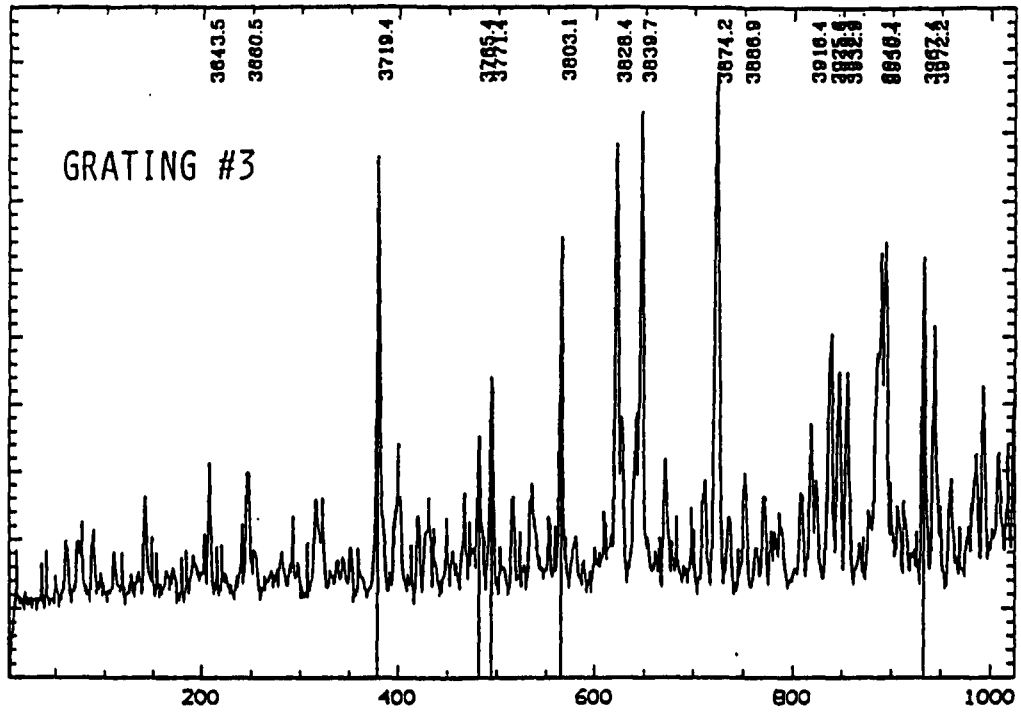


Figure D.7: *Th-Ar line identifications for gratings #3 & #11 centred at blaze position.*

Appendix E

Troubleshooting

Error messages are printed on the top and the bottom of the Ramtek UIF, and on the OBST console. A reserved area at the very top of the UIF gives error messages that need to be specifically cleared. For example, if OBST is assembled with the link to the NTT computer disabled, a message reading: `Assembly defined with NO access to: TELNTT` will appear in yellow, preceded with the time at which this particular condition was verified. Thus, normally the yellow messages on the UIF are for information and in most cases do not imply a catastrophic failure.

The messages at the bottom of the UIF inform you if the system expects input from the mouse or from the keyboard, and whether the parameters in the forms have been sent to the computer. Normally these conditions are cleared by simply sending the forms (using the RETURN or ENTER keys) before using the mouse. Sometimes, however, the terminal stays undefined and does not receive input from either the keyboard or the mouse. In that case, hit RETURN several times until the condition is cleared. If the terminal continues to be blocked, go to another terminal of the NTI computer (not NTT) and from CI type `CI> SETP,lu` where `lu` is the logical unit of the terminal you wish to unblock (usually written on the terminal itself). If this does not work, call Operations.

The third list of messages appears on the upper half of the OBST console. These messages contain information about the current activity of the system, as well as error messages. They are normally not ordered so you must check the time that is displayed together with the message to find the relevant ones. The error messages appear on inverted video and usually inform of some failure that prevents an exposure from being started (for example if a wrong parameter is given in one of the forms, or there is an ongoing exposure). Sometimes the message `Red Path is not free yet` appears without an exposure running. This is due to a bug in the system, which is best cleared by exiting from the program (soft-key `Exit` in the OBST terminal) and starting OBST again.

A common error message occurs when the IHAP database is full. The message `IHAP database full` appears before the exposure starts. In that case, the IHAP commands `PURGE` and `PACK` must be used to remove files and clear the disk space. Make sure that the files have been written on tape before using the `PACK` command. Files accidentally purged may be recovered usign the `FRESTORE` command, but this is no longer possible once `PACK` is used.

In general most problems with the UIF occur when you try to be too fast. It takes a certain amount of time to send all the information in the parameter forms to the computer, and the best way to avoid problems is to wait until the forms are sent before attempting to give other commands. Thus, after you fill the form, hit RETURN and wait for the audible signal before using the keyboard or the mouse.

Some times the frames arrive at the MIDAS workstation without descriptors (headers). This is due to a bug in the HP computers whereby a program called **AOIB** stops. This happens randomly and it is therefore recommended to check every afternoon if the descriptors are present (simply use the MIDAS command **READ/DESC filename ***. If the descriptors are not present, ask the night assistant to restart **AOIB**.

Appendix F

The NTT Active Optics System

Both the primary and the secondary mirrors of the NTT are actively supported. The active support of the primary (M1) unit consists of 75 actuators and three fixed point supports. The M2 support provides X,Y,Z (focus) motions. The force applied to each of the 75 actuators can be adjusted and thus the shape of M1 unit can be modified. The X,Y motion of M2 is used to correct for centering comma.

The image analysis sytems, located inside the instrument adaptor/rotators consist of a Shack-Hartmann grid and a CCD to record the images of the telescope pupil through the grid. Software running in the NTT computer reads these images, determines the telescope aberrations, and calculates the differential forces to be applied to the active support in order to correct these aberrations.

The night assistants are fully acquainted with the system and are responsible for its operation. It is useful, however, that observers be aware of the basic operational principles since they may be requested to take operational decisions on nights of excellent seeing.

F.1 Operational aspects

The NTT Active Optics System (AOS) is initialized every afternoon by the night assistant. In practice, this means setting the forces of the M1 support, and the position of the M2 unit to the default values which have been calibrated for zenith position. Normally, this procedure alone is sufficient to operate the telescope under average seeing conditions ($FWHM \sim 1''$). In order to monitor the stability of the system, and to check for possible problems, the night assistants are instructed to do a full image analysis shortly after sunset. The observers may decide to shift these measurements to later in the night if they conflict with the acquisition of twilight sky flat fields, but in general it is advisable to monitor the mirror settings at least once per night. A record of all active optics measurements is kept in the NTT control room.

For seeing conditions around one arcsecond there is no need to further check the AOS unless the images become severely elongated. The active optics control automatically corrects the position of the M2 unit as a function of zenith distance, while the primary mirror is sufficiently stiff to retain its shape without need for corrections.

Only when seeing conditions become very good should one worry about resetting the M1 support. This is normally done simply by enabling the automatic correction as a function of zenith distance which is normally disabled. This uses a look-up table to determine the optimal distribution of forces for the corresponding telescope position. This option is normally kept disabled because it adds an overhead of several minutes every time the telescope is pointed, and is not necessary unless the seeing conditions are very good. *Notice that, because the corrections are differential relative to the previous values, once the automatic correction mode is enabled, it should be used for every preset.* Thus, if the seeing conditions deteriorate, the telescope should be pointed close to the zenith before disabling the automatic correction mode.

If the seeing conditions become exceptional (e.g. 0.5″ or better), or if the conditions are good (e.g. $< 1''$) *and* the telescope is pointed to zenith distances larger than 30°, it is recommended to do a full image analysis using a bright star near the position of the target objects. A full image analysis plus correction takes about 10 minutes, but can be done during target acquisition.

F.2 Image analysis

A dichroic beam splitter has been installed that allows the image analysis system and the autoguider to work in parallel. The NTT control software can be set so that the system automatically searches for a bright star near the position of the objects to be observed (using the HST-GSC). In this way, the image analysis can be performed during target acquisition. This system is of great help under all seeing conditions because it allows precise automatic focusing of the telescope.

A typical image analysis output is shown in Figure F.1. The relevant parameters in the present context are the column labeled `rms`, near the top of the form, the line giving `d80` in the field `Transverse aberration`, and the `M2 movements for total correction`. The meaning of these parameters is as follows:

rms In order to improve S/N and to have a handle on the stability of the solution, $2-3$ frames are typically used in every image analysis run. `rms` is the standard deviation of these measurements and gives a good estimate of the seeing conditions (local+atmospheric). If the rms is large, the solutions are largely determined by atmospheric and dome seeing and therefore it is not recommended to reset the mirrors. Under very good seeing conditions the rms is below 0.12, while for very bad conditions the rms can be higher than 0.20. The recommended limit is 0.18 beyond which no corrections should be applied to the optics.

d80 This is the diameter within which 80% of the light is concentrated and is thus a direct measure of the optical quality of the telescope. The various components that contribute (quadratically) to d80 are shown. The principal terms are spherical aberration (`spher`), coma, astigmatism (`ast`), triangular coma (`tri`), and quadratic coma (`quad`). Defocussing is given but is not considered in the total sum. On nights of exellent seeing, the optical quality may be adjusted to d80 $< 0.1''$, but twice this value is still aceptable.

M2 movements This field gives the corrections to be applied to the position of the M2 unit. Normally only the Y (zenith distance) and Z (focus) should require corrections. The focus offset between the image analyser and the instruments has not yet been accurately calibrated.

After image analysis is completed, the computed corrections must be sent to the telescope and the program prompts for a decision after displaying the parameters on the screen. *Remember! Applying corrections when the rms is high may degrade the optical quality of the telescope instead of improving it!.*

There is a small offset between the telescope focus at the image analysis camera, and the focus at EMMI or SUSI. This offset has not yet been accurately measured, and therefore it is advisable to check the focus every time the optics are reset using the AOS. If the automatic M1 correction is enabled, the focus should be checked every time the zenith distance (ZD) changes by more than 10°.

```
                          Output merging program

mean of          2 measurements starting with # 343

 Time                :    0:52:41  92 1992
Analysis done in the  A D A P T E R  B


Defoc. Sph.ab. ----coma3--- ----astig--- ---trian--- ---quadr--- -ZD- rms  d80
 -375.3  -25.8  230.4-124.9  308.2 133.6  33.8   1.6  61.3 114.6 11.1 .12 .287
 -583.8  113.0  322.9-145.8  185.0 117.0  51.3 -95.4 118.4  76.4 11.0 .11 .282

Mean-------------------------------------------------------------------------
 -479.6   43.6  271.7 153.3  243.4 168.7  28.0  90.7   84.3  350.4
Standard deviation ..............................................................
  104.3   69.8   69.8         73.1        33.2         42.3
Recalculated standard deviations....................
  104.6   73.9   64.8         34.0        25.2         21.1
Average standard deviation of coefficients for single measurement :  48.0


Effects of uncorrected aberrations

     Defocus on detector  :    -813.6

     Transverse aberration :
              total      defocus   spher   coma    ast      tri    quad
  rms     :    .137        .126    .003    .026    .041    .006    .020
  d80     :    .346        .319    .008    .060    .103    .016    .057   .133
  d100    :    .391        .352    .010    .096    .115    .020    .079

     Wavefront :
              total      defocus   spher   coma    ast      tri    quad
  rms     :   250.1      -225.4     4.9    32.0    99.4     9.9    26.7

     M2 movements for unconditional total correction :
           in x_direction :    .052 mm
           in y_direction :   -.103 mm
           in z_direction :    .018 mm

Elastic aberrations to be corrected :
      astigmatism            :   243.4
      quadratic astigmatism  :    84.3

M2 movements for total correction :
           in x_direction :    .052 mm
           in y_direction :   -.103 mm
           in z_direction :    .023 mm

M2 movements for correction of defocus only :
           in z_direction :    .023 mm

 average tilt :     17419.0  354.0
 rms of tilt  :       530.4

----Tilt----- -X-- gp1 -Y- ----Rot A--- ---      --- ---         --- -  --
16964.2  63.8    0.   20.     32.2
17877.9  63.2    0.   20.     30.9
```

Figure F.1: *Sample output from the NTT image analysis program. The optical quality of the telescope is given in the* `Transverse aberration` *on field. The* `rms` *gives an estimate of the stability of the solutions which is determined by atmospheric and dome seeing.*