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THE BOLLER & CHIVENS SPECTROGRAPHS

The Boller & Chivens Spectrographs

M. Heydari-Malayeri

B. Jarvis

A. Gilliotte

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Chapter 1

Introduction

This manual describes the operation of the Boller and Chivens Spectrographs on La Silla equipped with a CCD detector. It is intended as a general practical guide to help observers in preparing and performing their observations. Our hope is to be brief and explicit, but also providing some self-evident points where they are important for obtaining high quality data.

First time users are advised to read this and the CCD manual carefully to get acquainted with the optical system, Boller & Chivens control program, detectors and observing techniques. The bulk of this manual deals with the general problems of spectroscopy at the three telescopes equipped with B & C spectrographs, i.e. 3.6m, 2.2m and 1.52m. Experienced users interested in specific practical remarks on observations at each telescope can go directly to Chapter 7.

All commands in this manual enclosed in a box [*like this*] denote "soft-keys" on the keyboard of the data acquisition computer.

We strongly encourage users to make any comments and suggestions concerning this manual in order that we may refine future versions. Please do this by firstly writing on a copy of this manual which you will find in the control room of the telescope and secondly in your observing report to be completed at the end of your observing mission to La Silla.

Chapter 2

System Description

2.1 Brief History

The Boller & Chivens (B & C) Cassegrain spectrographs available at La Silla are classical grating spectrographs. The first standard Perkin Elmer B & C spectrograph was installed on the 1.52m telescope in 1973. This version used a catadioptric camera from Perkin Elmer with a photographic plate as detector. Later on, new detectors were implemented, including Image Dissector Scanners (IDS), EMI image intensifier tubes, a Reticon, and finally CCDs. The original catadioptric camera has now been replaced with a Schmidt camera from Zeiss. A new dioptric camera is also now in use at the 1.52m telescope.

Presently, B & C spectrographs are available on La Silla at the 3.6m, 2.2m and 1.52m telescopes with 31 gratings, allowing a good coverage in both dispersion and wavelength within the CCD sensitivity ranges. The observer can communicate most of the commands necessary to control the spectrographs through a display console in the control rooms of the three telescopes. Where differences occur, these are indicated in the appropriate sections of this manual. The full automation of the 1.52m spectrograph is still in progress. The B & C spectrograph is also used with the OPTOPUS at the 3.6m telescope for multi-object spectroscopy (see the OPTOPUS operating manual for details).

2.2 Optical Systems

The three B & C spectrographs are all of similar optical design (see Fig. 2.1). The optical parameters of the instrument for each telescope are summarized in Tables 2.1 and 2.2 The converging light beam from the telescope passes through the spectrograph entrance slit in the telescope focal plane to the collimator, an off-axis parabolic mirror. The reflected parallel beam then falls on to the grating surface. The diffracted light passes through a Schmidt camera which images the spectrum on to the CCD detector.

The slit assemblies consist of two 64mm long polished and aluminized jaws on which the stellar image can be seen by reflection. The slit jaws form a biparting slit that is continuously adjustable by a micrometer screw from 50 to 1200 μm. At the 3.6m and 1.52m telescopes, the slit jaws must be manually set. The slit-width at the 2.2m is remotely controlled from the observing console in the control room. Note that the slit appears smaller to the detector than is the real width (called projected slit-width). This is due to two effects. Firstly, because of the transversal magnification factor, γ, (the ratio of the camera to collimator focal lengths, see Table 2.1), and secondly, to the grating anamorphism. This anamorphism, or demagnification, is shown in graphical form in Fig. 2.2. The apparent reduction in slit-width can be compensated for by selecting the required resolution at the detector and calculating back the slit-width. For example, if we require a projected slit-width on the CCD detector of 30 μm (2 x 15μm pixels) then the real slit-width should be $30/(0.78 \times \delta\ (= 0.191)) = 201\mu$m. Here we assume that we are working at a grating angle of 15^o.

The opto-mechanical configuration allows for a fixed angle between the incident and diffracted beam axis of the grating (grating angle α). The grating is mounted in an adjustable rotating cell that permits the choice of the central wavelength and spectral orders.

The spectrograph cameras currently in use at the 3.6 m and 2.2 m telescopes have a focal length of 143.5 mm and are optimized for use over the range 3200–12000 Å where they have an efficiency of about 50 - 55 %. Below 3200 Å, the efficiency drops rapidly to $\sim$ 10 % at 3000 Å. A field-flattening lens is also mounted immediately in front of the CCD dewar in order to correct for camera field curvature. At the 1.52 m telescope an f/2.8 dioptric camera was recently installed (Feb. 89). It has an average efficiency of 80% between 4000 and 6000 Å and greater than 60% between 3200 and 10000 Å.

An order blocking filter assembly is located below the slit jaws to prevent overlapping of unwanted spectral orders. The 3.6m and 1.52m spectrographs have provision for holding two different filters. The 2.2m spectrograph may hold up to four filters. The correct choice of filter is normally determined by the optical group and installed before an observing run. The choice of filter can also be made by the observer by using Fig. 2.3 which shows the physical placement of the spectral orders in the image plane of a spectrograph.

No deckers are used with the B & C spectrographs for observation. There is a decker mounted in front of the slit, but this is used for setup purposes only.

2.3 Detectors

Only CCD detectors are at present offered with the B & C spectrographs at La Silla. An Intensified Reticon Photon Counting System (RPCS) detector is occasionally used at the 2.2m telescope.

The CCDs available at the time of writing on La Silla for spectroscopy are high and low resolution RCA and GEC chips. Thompson chips may also soon be available. The formats

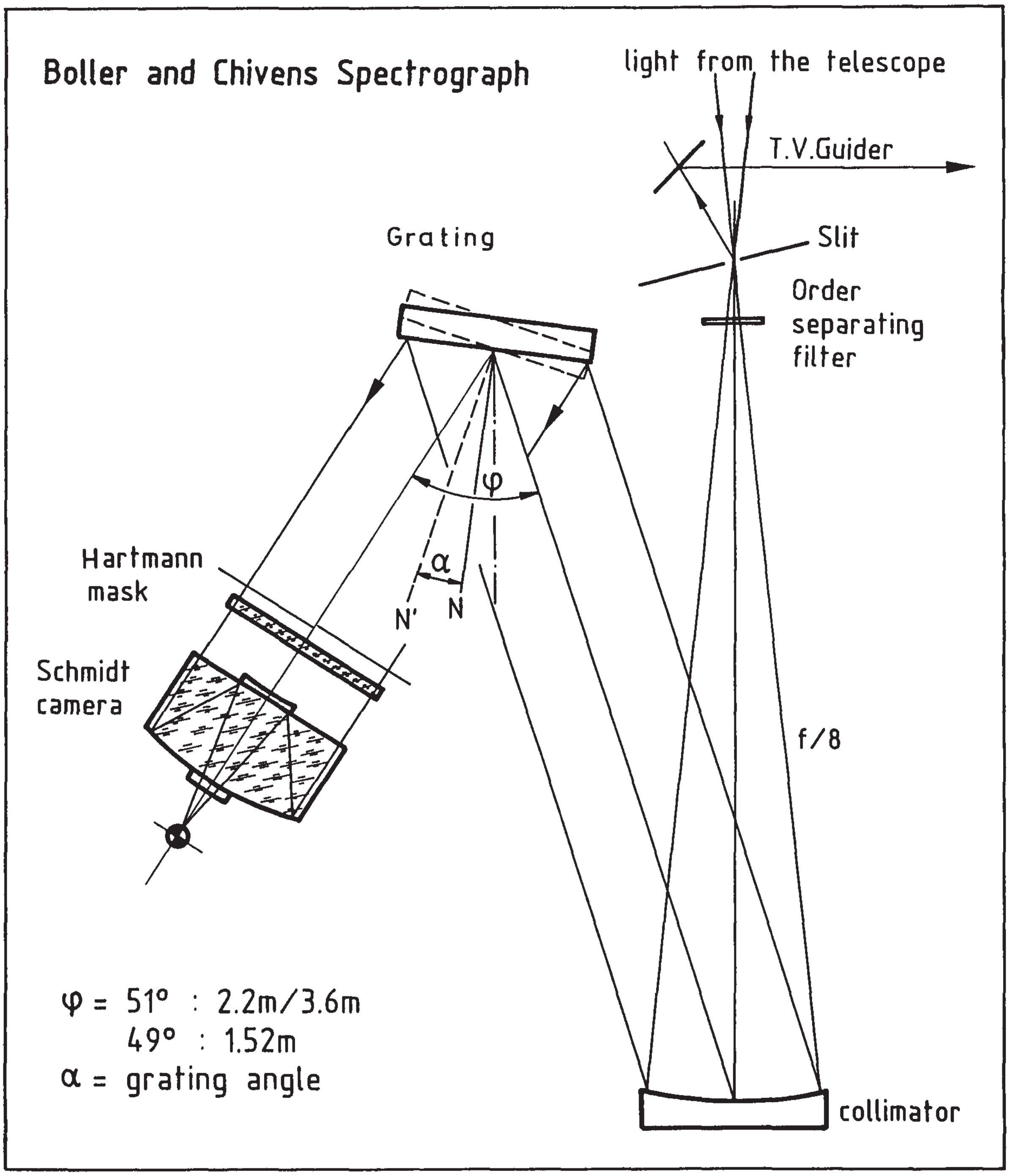


Figure 2.1: Boller & Chivens spectrograph layout

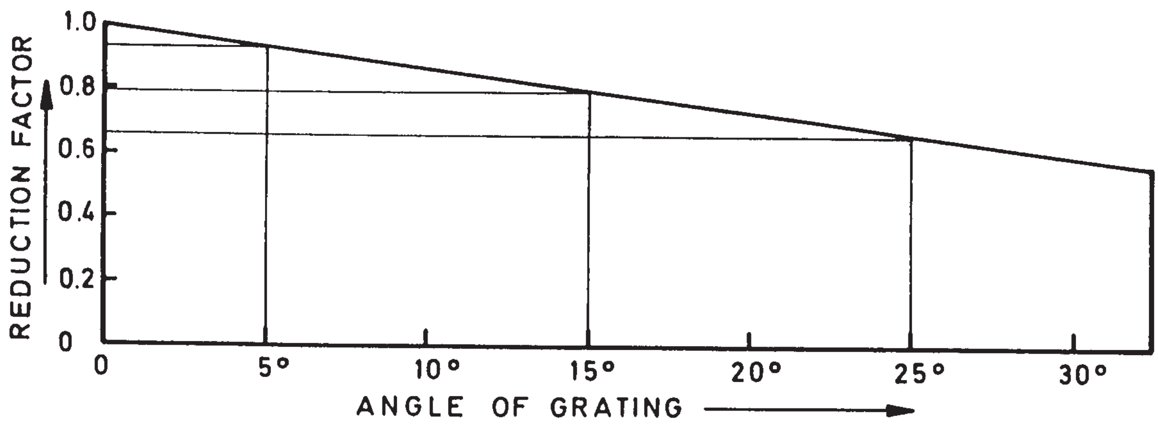


Figure 2.2: Demagnification vs Grating Angle

range in size up to 1024 × 640 pixels (15.36 × 9.60 mm). The detailed characteristics of the available CCDs can be found in the ESO CCD Manual.

2.4 Calibration Lamps

Two calibration lamps are mounted at the 3.6m, 2.2m and 1.52m telescopes, one blue halogen lamp for flat-fielding and one Helium-Argon spectral lamp for wavelength calibration. Lamp selection and illumination are done remotely at all three telescopes. A neutral density wheel is also available at the 2.2m and 1.52m telescopes if needed. These can be used to attenuate both the He-Ar and the internal flat-field lamps. For the practical use of the calibration lamps see Chapter 7.

2.5 Instrumental Rotation

The Cassegrain adapters on all three telescopes can be rotated up to 180° in either direction. The instrumental rotation is remotely controlled only at the 3.6m telescope. For the 2.2m and 1.52m telescopes, the rotation has to be done manually in the dome. Both these latter Cassegrain adapters have scales for accurately setting the position angles of the spectrograph slit. Instrument rotation can be done with the 3.6m telescope at any zenith distance. However, since the rotation at the 2.2m and 1.52m telescopes are done

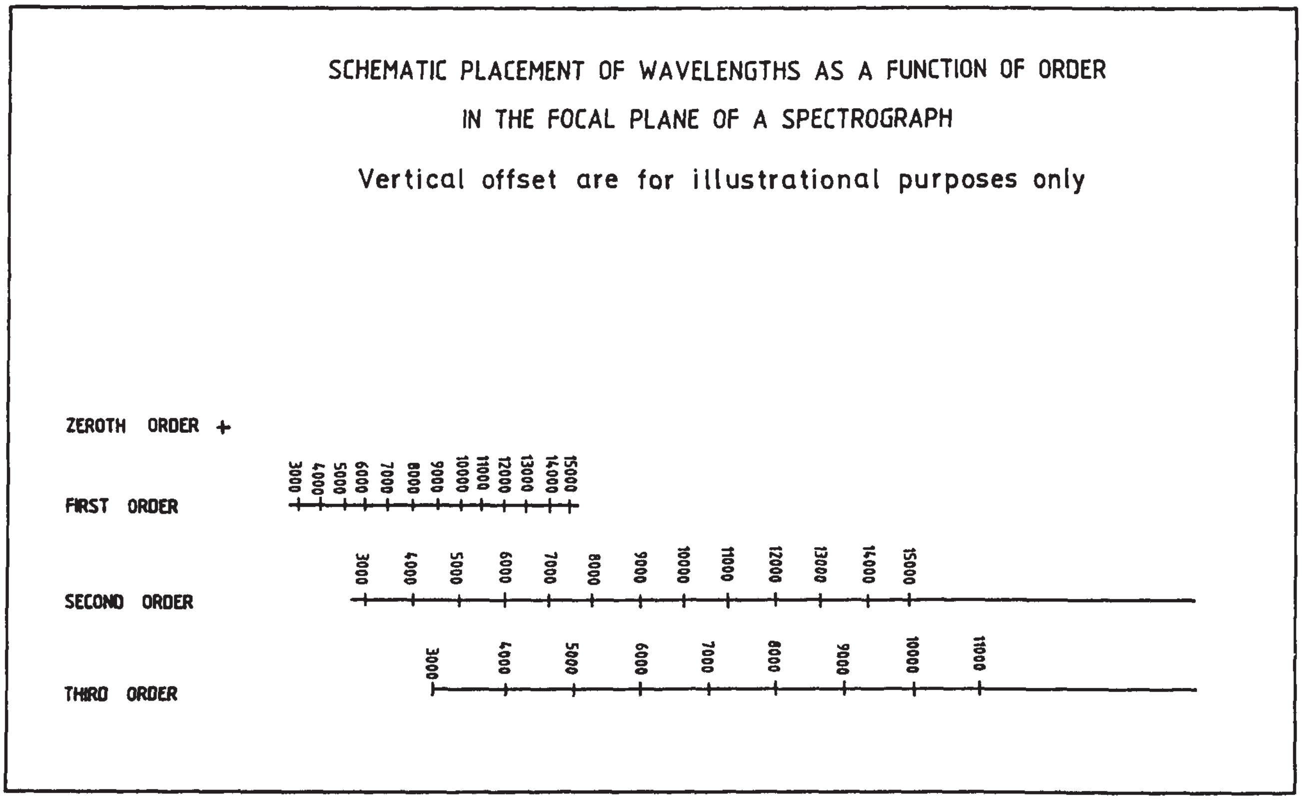


Figure 2.3: Schematic placement of orders as a function of wavelength in the focal plane of the spectrographs.

manually, this is usually done with the telescopes at the zenith to facilitate reading of the position angle scale on the Cassegrain adaptor. This is particularly important for the 2.2m telescopes, since, once the spectrograph is unclamped ready for rotation, it may start to rotate rapidly as the spectrograph is not balanced about the optical axis. Particular care should also be taken while rotating to ensure that the cables do not become caught on the telescope or instrument. For safety reasons, the rotation of the spectrographs should be supervised by the night assistant.

2.6 TV Acquisition and Guiding

The front surfaces of the spectrograph slits are aluminised and tilted slightly with respect to the incoming beam to allow the use of an integrating TV acquisition and guiding system. See Table 2.2 for the approximate fields-of-view of the TV cameras. At the 3.6m telescope there is an integrating autoguider looking at the front of the slit. There is also a "field-viewing" position (approximate field, 5′ x 4′) for object acquisition. A V $\simeq$ 20 mag star can be seen without integration on a moonless night on the center field camera. The 2.2m telescope also has an intensified camera for autoguiding. Under good moonless conditions stars of V $\simeq$ 18 can be seen. Finally, at the 1.52m, guiding must be done by hand. There is an intensified TV camera which will allow stars of V $\simeq$ 16 to be seen under good conditions. Note that these are approximate magnitudes and critically depend on focusing, seeing etc.

Table 2.1: Optical Parameters

Telescope Aperture (m)	*Telescope f-ratio (f/)*	*Slit Scale (″ mm^{-1})*	*B & C f-ratio (f/)*	*Collim. Focal Length (mm)*	*Grating Conf. Angle (°)*	*Camera Focal Length (mm)*	*Transversal Magnification Factor, γ*
3.6	8.09	7.2	8.3	750	49	143.5	0.191
2.2	8.01	11.7	8.3	750	49	143.5	0.191
1.52	14.9	9.2	7.0	630	51	127.0	0.202

Table 2.2: CCD Detector Parameters

Telescope (m)	Spatial Scale (″ pixel^{-1})*	Slit length (′)	T.V. f.o.v.
3.6	0.55	2.9	3′ × 3′
2.2	0.89	4.9	3′ × 3′
1.52	0.68	4.2	1.5′ × 1.1′

* 15 μm pixels

Chapter 3

Boller & Chivens Performances

3.1 Available Gratings

The Observatory has 31 gratings available. All gratings are 110 x 135 mm and are used mostly in the first and second order with dispersions ranging from 29 to 450 Å mm^{-1}. The detailed characteristics of each grating are given in Appendix B. In principle, all gratings are available at the 3.6m, 2.2m and 1.52m telescopes. It is important to specify in your observing proposal which grating(s) you require, since, in the event of a conflict with other telescopes, priorities are determined by telescope size.

For some gratings, the astronomer *must* consider the different efficiencies encountered for the polarization directions both parallel and normal to the grooves, especially for highly polarized objects. For most astronomical observations, however, the average between the two polarisation efficiencies is sufficiently accurate. Since the grating angle for a given central wavelength depends only upon the grating's number of grooves mm^{-1}, we present in Appendix D plots for calculating the grating angle for any desired central wavelength.

3.2 Spectral Coverage

The grating dispersion, camera focal length, and detector size determine the observable spectral range. For example, grating # 21, which has a dispersion of 172 Å mm^{-1}, when used in the first order will provide a spectral coverage of $172 \times 15.36 = 2642$ Å with a high resolution RCA chip ($1024 \times 15\ \mu m = 15.36$ mm). Given that the grating is centered at λ 5400 Å, the wavelength limits will be 4079 Å and 6721 Å.

3.3 Spectral Resolution

The *theoretical* spectral resolution depends on the grating dispersion, grating position, pixel size, collimator and camera focal length, and entrance slit-width. The *effective* CCD spectral resolution also depends on the detector sampling. See Appendix A for a detailed calculation of these parameters.

As an example, grating #21 (blaze angle 6°54') will have *theoretical* resolutions of 1.72 and 3.45 Å for slit-widths of 1″ and 2″ respectively. Decreasing the entrance slit-width will improve the resolution. However, this will be possible only when the sampling requirements (Nyquist criterion; one resolution element imaged onto at least two detector elements) are respected and also when the instrumental response is not diffraction limited.

3.4 Spatial Resolution

The spatial resolution depends on the transversal magnification factor of the spectrograph given in Table 2.1. (This spatial scale can easily be determined by moving a star a known distance along the slit and taking an exposure at both positions. This operation is commonly done using the *Pause exposure* softkey to get both spectra on the same image). Table 2.2 gives the spatial scales for the three telescopes equipped with a B & C spectrograph.

The CCD control program allows the CCD pixels to be binned in either direction (spatial or dispersion) before reading out. This can be an advantage when your objects are faint in which case you may want to bin in the spatial direction. No spectral resolution will be lost but there will be a decrease in the read-out-noise by a factor of the square root of the number of pixels binned. Therefore, this may allow the use of shorter exposure times and higher signal-to-noise ratios at the cost of decreased spatial and/or spectral resolutions, depending on which direction you are binning. Also, binning increases the risk of cosmic ray events influencing data since several pixels are averaged before readout. Furthermore, binning also reduces the contrast of particle events making automatic removal more difficult. Should spectral resolution be of vital importance, bin the chip only along the X (spatial) direction. See the ESO CCD manual for a full description of binning.

The CCD program also allows "readout windowing". This means that only those pixels within a predefined window or area on the chip are recorded. The spectrograph slits do not extend across the entire width of the CCDs and therefore no information is contained outside the length of the slit. Windowing can thus provide significant savings in the sizes of your data files and image display time.

Every day in the afternoon, before starting your calibration exposures, check to see that the binning and windowing of the chip is what you need. The CCD binning may have been changed by the technical group for test purposes. This is done using the softkey *CCD frame/binning* (see section 4.2).

3.5 Grating Efficiencies

The efficiency as well as the dispersion at the desired working wavelength is an important parameter when choosing a grating. The efficiencies of the available gratings have been measured experimentally and are shown in Appendix C. Note that the *total* system efficiency is the combination of the efficiencies of the telescope, spectrograph, grating, camera and the detector.

3.6 Exposure Guide

While it is impractical to provide an exposure guide for all gratings in all wavelength ranges with all available CCDs and at all gains etc, we provide some rough guidelines from which it should be possible to estimate approximate exposure times for your objects by taking into consideration the different grating efficiencies, CCD detector quantum efficiencies etc.

3.6.1 Total efficiency

The total telescope efficiency is the ratio of the number of detected photons divided by the number of incident photons entering the telescope. This latter quantity is found for standard stars from:

$$N_\lambda = L \times \frac{4.5 \times 10^{10}}{\lambda} \times 10^{-0.4(m_\nu + A_\lambda x)}$$

where, L is the telescope primary mirror area in square meters and N_λ is the number of photons at wavelength λ incident on the telescope per second and Angstrom. A_λ is the mean extinction coefficient and x is the airmass. The values of m_ν are found from tables of standard stars.

3.6.2 Expected S/N ratios

The *expected* S/N ratio obtained by a CCD with a finite read-out-noise and dark current, is:

$$S/N = \frac{3600 n_0 t \times 10^{-0.4(m-m_0)}}{(3600 n_0 t \times 10^{-0.4(m-m_0)} + (wb^{-1}N_r)^2 + w^2 tD)^{0.5}}$$

where

n_0	=	efficiency in $e^-s^{-1}pixel^{-1}$ for a star of magnitude, m_0.
ω	=	width of the spectrum in pixels, perpendicular to dispersion
N_r	=	read-out-noise in e^-pixel^{-1}
D	=	dark current in e^- $pixel^{-1}$ hr^{-1}
t	=	exposure time in hours
b	=	binning factor perpendicular to the dispersion direction.
m	=	stellar magnitude

3.6.3 Measured S/N ratios

Figure 3.1 shows the *expected* growth of S/N ratios as a function of V magnitude with exposure time for the 1.52m telescope based on the formula above. These curves were constructed using grating 10 with CCD#13 at a gain of 20 ($\simeq$4.1e^-ADU^{-1} and with b=1 and ω=3). These curves are for a wavelength of 5556Å and will of course be different for other CCDs, effective wavelengths, and gratings etc. They serve only to give an approximate guide as to what may be expected. In addition, a few datapoints obtained with a wide slit, are shown. Note that these data were obtained before the new camera was installed and hence will be somewhat different from the current set-up. The new camera has an increase in throughput approximately 3.5 times that of the old camera. The exposure times in Fig. 3.1 should then be compensated by this amount to determine the approximate S/N ratios with the new camera.

Similarly, Fig. 3.2 shows the same for the 2.2m telescope based on grating 15 with CCD#7. As stated above, these curves should be used as rough guides only. A similar curve will be provided for the 3.6m telescope when suitable data becomes available.

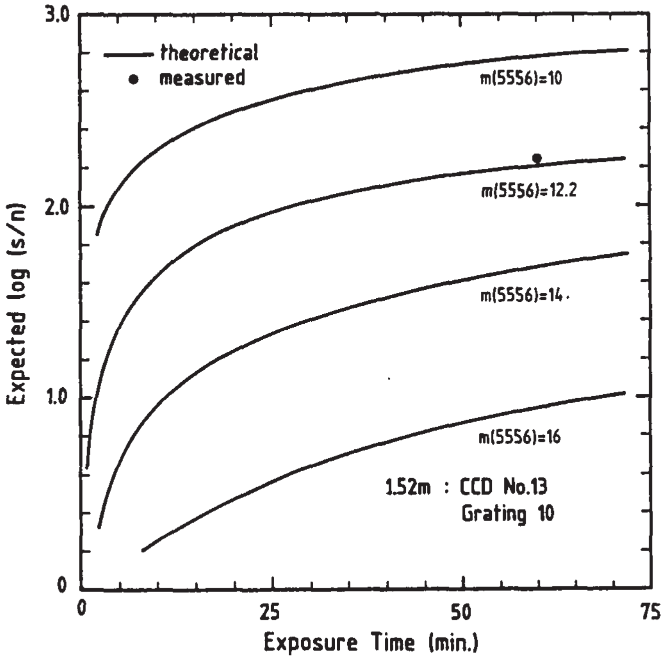


Figure 3.1: Expected S/N ratio vs exposure time for the 1.52m telescope at 5556 Å

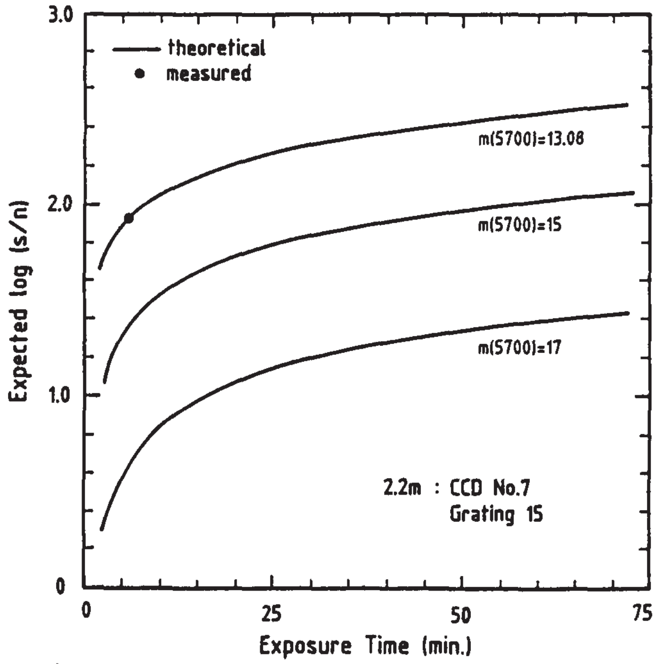


Figure 3.2: Expected S/N ratio vs exposure time for the 2.2m telescope at 5556 Å

Chapter 4

Set-up and Observations

4.1 Instrument Set-up

The operations group (paging 93, 54) at La Silla must receive your grating request with specifications (filters, slit-width, etc.) the day prior to your observing run. If necessary, ask advice from your introducing staff astronomer on how to fill out the grating request form. The forms are available in the Astronomy Lounge if you did not already receive one upon your arrival at the ESO guesthouse in Santiago (Appendix H shows an example of the request form).

The Operations Group will do the instrument set-up in the afternoon of your first observing day. They will adjust the grating angle for your requested range and will align the dispersion direction along the CCD columns. They will also adjust the spectrograph collimator focus for the requested range and generally check that everything is working properly. Usually you can start your flat field and calibration exposures at about 4 pm. It is the observers responsibility to check that the grating is set at the required wavelength range. If he wishes, he may also check the focus of the spectrograph himself (see Appendix I). Any problems should be immediately communicated to the Operations Group.

4.2 B & C Control Software

After access to the B & C acquisition program (Chapter 7), set-up, maintenance, and actual observing can then be controlled by a number of self-explanatory "menus" and by filling forms. The format and most of the options are similar to those of other ESO instruments. The most frequently used softkey is *Define exposure* for specifying the exposure type (regular, flat-field, dark, calibration) and other parameters used to define the exposure. It is also possible to define sequences of exposures. These are useful when doing flat fields, dark exposures etc.

The softkey *CCD frame/binning* allows the choice of the binning factor along the rows and columns of the chip. This softkey is used also for selecting the readout window of the CCD and is reached by pressing the following sequence of softkeys from within the B & C control program: *Previous Menu*, *Terminate*, and *CCD* and then the *CCD frame/binning* softkey. This will help you to use just that part of the chip containing useful information, avoiding large data files.

4.3 He-Ar Calibration

All spectrographs are equipped with a He-Ar calibration lamp. One of the first things you should do in the afternoon of your first observing night is to check the wavelength range you have asked for.

A high signal-to-noise He-Ar spectrum is necessary for a good wavelength calibration. A fixed exposure time cannot be given for the calibration arc since this depends on the grating dispersion, intensity of the lamp, and slit-width used. All three telescopes have remotely controllable neutral density filters which can decrease the intensity of the lamps if necessary. In general, however, these are rarely required. Typical exposure times range from 5s to 60s depending on the grating, gain used etc. Start with short integration times to avoid saturation by strong Ar lines. Do multiple integrations to improve the S/N of the fainter lines if convenient.

Users interested in radial velocity measurements should take He-Ar spectra before and after each science exposure to closely monitor telescope flexure. In the following sections we present general considerations on calibration exposures. See chapter 6 for practical advice.

4.4 Flat-Fields

Flat-fields can be obtained with internal or external lamps at the 3.6m, 2.2m and 1.52m telescopes. While there is no agreement on the way to obtain the best flat-fields, experience has shown that flat-fields using a white screen inside the dome illuminated by a floodlight have good uniformity. The screen should not be illuminated directly, since you may get unwanted reflections in your flat-fields. Consequently, turn the lamp away from the screen. The longer exposure times needed will be compensated by obtaining better flats. The exposure times depend on the grating used, light intensity, CCD binning, slit-width and the chip type. The best exposure times are those which give approximately the same number of counts as obtained in your science exposures. If this is not known *a priori*, it may be advisable to take several sequences of flat fields with different exposure levels.

Flat-fields can also be obtained using daylight in the 3.6m and 1.52m telescopes. Just open the catwalk door slightly. We do not recommend opening the door to the access ramp of the 2.2m telescope especially when it is windy. The mirror may suffer from dust impacts, since the telescope is not well protected.

4.5 Electronic Bias

The analog output signal from the CCD is given a fixed offset before it is converted to digital values. This *bias level* should be checked during the observing run and should be approximately 200 ADU. The bias is determined from a zero-second "dark" (DK) exposure. It is advisable to median filter three or more bias exposures to improve the signal-to-noise ratio and also to reject cosmic ray events. This exposure is also used in determining the read-out-noise of the CCD chip. The *bias level* to be subsequently subtracted from all the science exposures is the mean of this median filtered image, i.e. one number only. The amplitude of the bias fluctuations represents the read-out noise.

4.6 Spectrograph Focus

The focusing of the spectrograph (camera and collimator) is carefully done by the operations group on the first day of your run. However, the observer, if he wishes, may perform his own check of the focus. The procedure for doing this is given in Appendix I. In the unlikely event that you believe the spectrograph may be out of focus, **do not attempt to adjust anything yourself**, but call the operations group (93, followed by 54) for advice. The focusing is affected by both the collimator and the camera: the reason for an out-of-focus image is best determined by the operations group.

4.7 Telescope Focus

The telescope focus should be performed at the beginning of the night before the science exposures and should be checked during the night, especially if temperature variations occur. The focusing is done by making several exposures of the same test star. Use a wide slit to eliminate problems due to centering, guiding etc. Between each exposure, the telescope focus is moved by a known amount and the star moved along the slit. You can use the *Pause exposure* softkey in order to put all the exposures on one image. The IHAP commands `SADD` (average rows) and then `SLCENTER` (determine FWHM of image) will allow you to determine the best focus (minimum FWHM). Ideally, this corresponds to the best focus on the TV screen, but this is not always the case. For relatively small temperature changes at the 2.2m telescope, the focus can be adjusted according to –20 units per degree Celsius increase. Ask the night assistant to say you how to obtain the telescope temperature.

4.8 Science Exposures

Important points to note when making your science exposures:

- Be sure of the slit-width you are using. This is particularly important for spectrophotometric exposures.
- Do not confuse the slit orientation (EW, NS, etc.). This is important for extended objects.
- Observation of spectrophotometric stars are essential for deriving the response curve of the detector. A good calibration requires observation of at least three standard stars each night. Depending on the seeing, use the appropriate slit-width in order to allow the total flux of the standard star to fall through the slit. A 10″ slit is normally OK for doing the flux calibration. The choice of the standard star depends mainly upon the wavelength range that you are using. Carefully check before making your exposures that the standard star has a sufficient number of calibration points and resolution for your purpose in the wavelength range of your spectra. Note that only a few stars are calibrated up to 10,000 Å.

Chapter 5

Spectrograph and Detector Characteristics

5.1 Ghosts and Anomalies

Image ghosts and anomalies originate from both the grating and spectrograph. These spurious images are frequently observed with ruled gratings. Such grating ghosts are caused by periodic variation in the position or shape of the grooves. Two different types of ghosts exist depending on the periodic defect. Long-term errors of the grating ruling machine produce the line satellite ghosts, while short-term errors bring about more dangerous ghosts appearing far away from the parent line. It is often difficult to identify these ghosts especially those coming from short-term periodic errors. The line satellite ghosts perturb the line shape due to the distortion of the line wings and so increase the width of the grating point spread function. Consequently, the observer should be very careful in looking for faint or unidentified lines, especially when observing objects with strong emission lines.

Spectrograph ghosts are produced by internal reflections between the optical surfaces. There are two types of reflection ghosts. The first type shows up as a real, focused spectral line, whereas the second one appears as a de-focused line. In order to minimize these reflections, all the optical elements have been coated, but unfortunately strong emission lines can still produce parasitic images. We have noticed some ghosts on all ESO B & C spectrographs. At grating angles close to 24°.5, an internal reflection appears between the grating surface and the first camera surface since at this angle they are parallel (Fig. 2.1). The ghost spectrum is reversed and superimposed on the parent line. At grating angles close to zero, internal reflections from the grating zero order produce nonuniform stray light.

Apart from the ghosts, the grating efficiency curves often show irregularities called Wood anomalies. These anomalies depend strongly on the polarization of the incident light and are most prominent when the polarization is perpendicular to the grooves. (See Appendix

C for the efficiencies of the gratings in the light of two different polarizations). A flat-field exposure can be used to visualize such efficiency irregularities, allowing their correction. The observer must take care of this defect when studying strongly polarized objects.

5.2 Dark Current

Electrons are created in silicon not only by incident photons but also by thermal effects. These give rise to dark current: the signal generated in the absence of any input light source. Its magnitude depends critically on the quality of the silicon used and on the processing procedures used to manufacture the device. Cooling the CCD dramatically reduces dark current. The dark current should be subtracted from the science exposures. For most applications the dark current is so low that it can effectively be ignored.

Use option `DK` when defining your dark current exposures. It is advisable to obtain several long DK exposures, of the order of one hour or more to obtain a good knowledge of the structure of the CCD, especially if such long exposures are used for your science frames. The IHAP command `FCOMPARE` and MIDAS command `AVERAGE/WINDOW` on two exposures can be used to remove the cosmic rays using more than one frame.

5.3 Cosmic-Ray Events

High energy particles generate muons, which deposit around 80 electrons μm^{-1} in silicon. With a collection depth of 10-20 μm, a cosmic-ray event is seen on a CCD image as having a signal of up to a few thousand electrons, usually concentrated in one or two pixels. In devices where the collision depth is greater and events are more diffuse, the removal of these electrons can be more difficult.

Cosmic rays can sometimes produce false lines with normal Gaussian profiles in GEC chips. Be very careful when you are searching faint spectral lines. The best method of removing cosmic ray events is the median filtering of a stack of (3 or more) exposures of the same object. Note also that when binning is used, the recorded "pixels" are more prone to cosmic ray events since they show a larger cross-section to incoming particles and the contrast by which the "hit" pixels differ from others is reduced.

5.4 Interference Fringes

Fringes are produced by interference effects between the silicon substrates within the CCD. The fringe pattern depends on the CCD type, the quality of the chip, and the wavelength range used. Fringes also appear in flat-field exposures, as illustrated in Fig. 3.1. They are most prominent towards the red and are almost negligible in the blue. The amplitude of the fringes produced by an RCA chip are $\sim$ 10–15% around 8000 Å (see Fig. 5.1). Fringing is much reduced for front-illuminated GEC chips, even in the red.

The effectiveness of fringe removal depends upon the reduction method used. (See ESO CCD manual). The fringes in the red can, in general, be corrected with an accuracy of better than 3 % when appropriate methods are used.

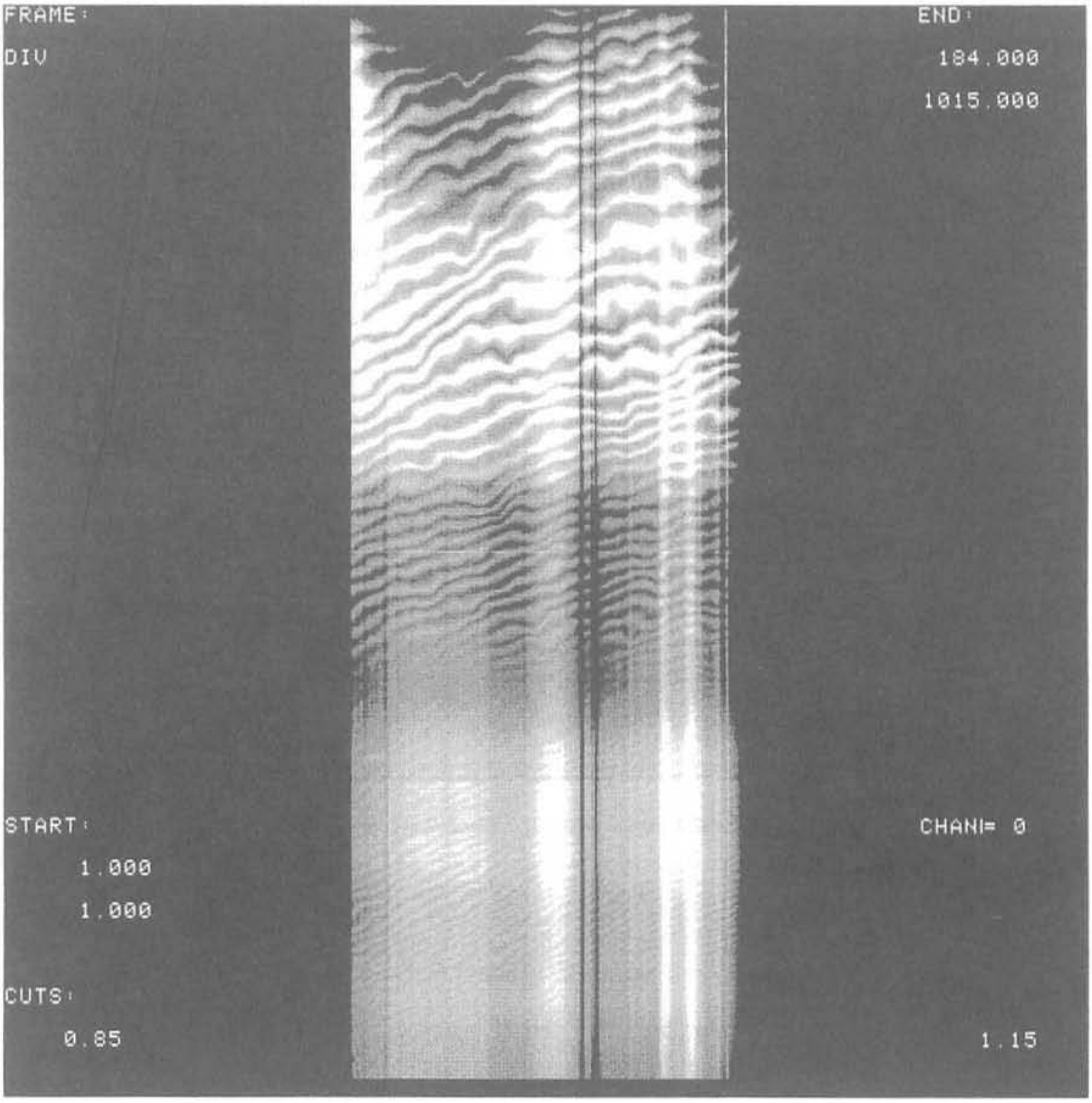


Figure 5.1: Interference fringes produced with CCD # 13 (RCA) at the 1.52m telescope. The grating used was # 15, with a spectral range ~ 6500–10000 Å.

5.5 Instrumental Flexure

Instrumental flexure is an important consideration for those observers attempting accurate radial velocity measurements. Since the spectrographs, which are not totally rigid structures, experience gravitational forces in directions depending upon the position of the telescope, shifts in the spectral lines on the CCD will occur. In general, relative to the position of the lines at the zenith, the magnitude of the shift depends upon the zenith distance of the telescope and also the position angle at which the spectrograph is set. Tests done at the 3.6m and 1.52m telescopes show that the flexure is less than 0.4 pixels (15 μm pixels) over 5 hours of hour angle with the slit in any direction. With the slit N-S, the flexure at the 1.52m telescope is about twice as large as it is with the slit in an E-W direction, but still less than 0.4 pixels. However, constant monitoring of the flexure by taking frequent He-Ar exposures can considerably reduce this. Wavelength calibration fits using third order polynomials typically have residuals of less than 0.2 pixels, which, with the higher dispersion gratings at 59 Å mm^{-1} correspond to a velocity residual of less than 10 km s^{-1} (see also Fig. 6.1).

Chapter 6

Miscellaneous Comments and Advice

6.1 Trouble-shooting

The night assistants are able to solve minor problems encountered during the observing night with the data acquisition system and the telescope. Do not hesitate to ask their advice if you have problems. In case they cannot solve the problem, the intervention of the Operation Group may be requested by paging number 93, then 34 (night) or 54 (day). The "astronomer on duty" (paging 93, 23) may also be called for advice on how to proceed or for questions of a more scientific nature.

Please report all problems in the night report. This is very important for solving and following the evolution of problems and benefits both you and other observers.

6.2 General Checklist

Here we summarize a number of important points to be checked during the observing run, especially at the beginning of each night. Ask the help of the Operations Group (Paging 93, 54) if you are not clear about any of these. Check:

- order separating filters, neutral density filter are out
- presence or not of neutral density filters in the calibration lamps
- binning factor of CCD
- read-out frame area
- CCD temperature

- slit-width
- CCD dewar is tightly mounted on Schmidt camera
- alignment of CCD with slit (operations group)
- spectrograph focus (operations group)
- *both* Hartmann shutters are out
- spectrograph entrance shutter (on Cassegrain adapter)
- mirror cover is open
- constancy and flatness of bias frame
- wavelength range
- telescope focus (at night!)
- where your object falls on the CCD (to avoid bad columns etc)
- UTC time written on the first exposure (cf CERME clock)
- Run star down slit to check E-W or N-S
- Open slit for flux calibrations ($\sim 10''$)

6.3 Atmospheric Dispersion

Atmospheric differential refraction is an important phenomenon often overlooked by observers. In simple terms, differential refraction means that at nonzero zenith distances an object cannot be simultaneously placed at the same position within a slit at all wavelengths. This problem becomes more important for increasing airmass, larger spectral range, and smaller slit-widths. Atmospheric differential refraction has particularly important implications for spectrophotometry and high spatial resolution spectroscopy. In particular, care should be taken that the spectral response of the television acquisition system matches that of the spectral region in which you are observing or that steps be, in appendix F, taken to correct for this. In order to minimise these problems, we give some general advice and show a table whereby observers can estimate the magnitude of this phenomenon for their objects. For a more detailed discussion the observer is referred to the article by A. Filippenko (1982: *Pub. Astron. Soc. Pac.*, **94**, 715).

6.4 B & C Data Reduction

Observers can make a quick evaluation of the quality of their spectra using the IHAP facilities at the telescopes. A full reduction of the B & C CCD spectra is possible using the IHAP or MIDAS packages (using context 'CCD') running on the HP and VAX computers, respectively. A detailed account of how to reduce these data is beyond the scope of this manual.

The method used for the data reduction strongly depends on the nature of the research program. Here we deal briefly with the wavelength calibration and the response curve of one CCD chip. The methods to be used are explained in detail in the IHAP Manual.

In order to get a good wavelength calibration, avoiding large residuals, we recommend that you prepare a wavelength table containing the main lines in your spectral range (see Appendix E). As examples, we present here two calibration curves obtained for gratings # 26 and # 21 (Fig. 6.1).

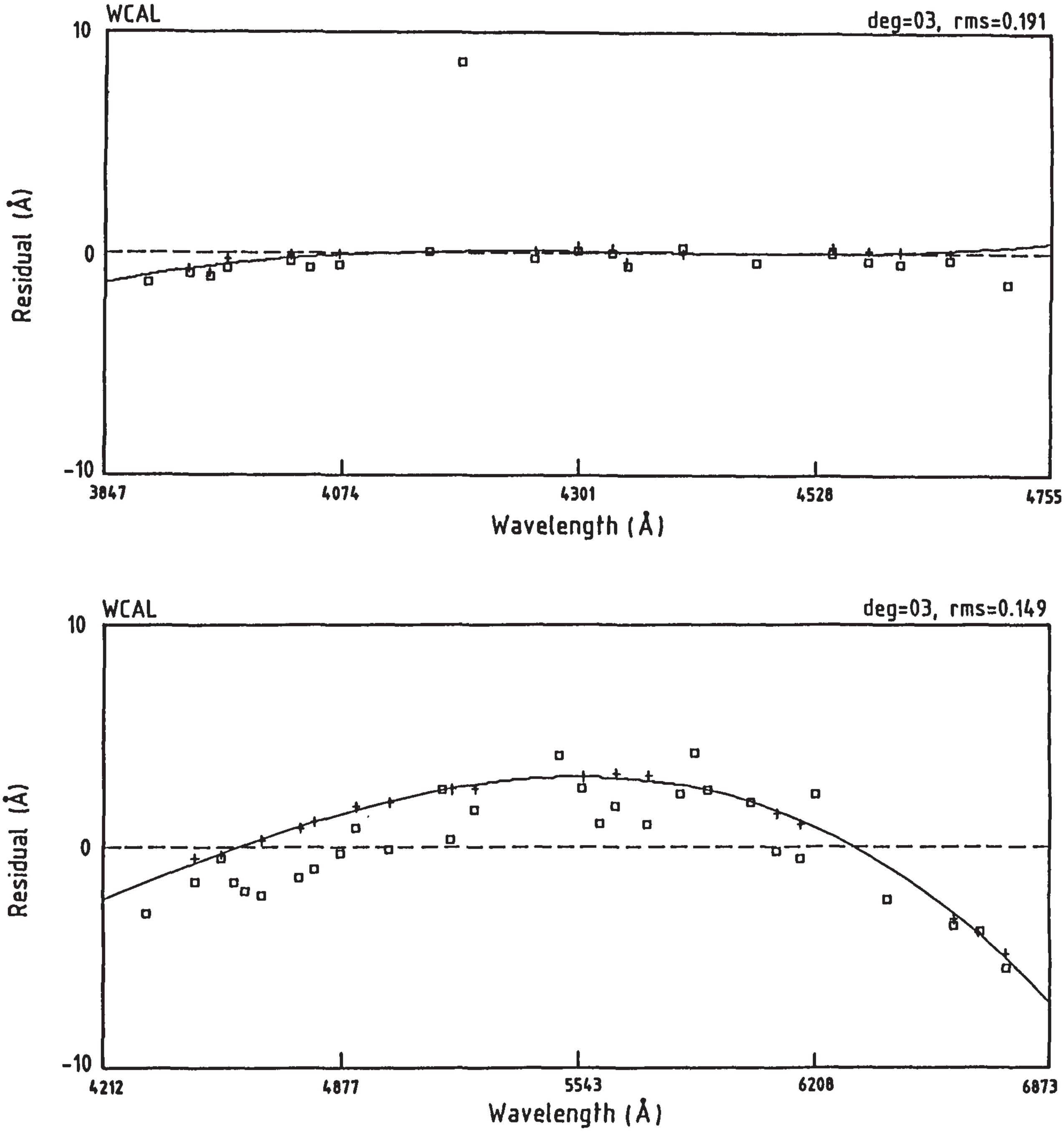


Figure 6.1: Calibration curve for gratings # 26 (a) and #21 (b) used with CCD # 5 at the 2.2m telescope.

For a good determination of the spectral response curve one needs to observe several standard stars with a relatively wide slit in order to gather all of the flux. Firstly, correct the spectra for the dark current and normalize using your flat-fields. Then sum up all the pixels in the spectrum (using `XADD` command) and correct for the corresponding sky contribution. Do the wavelength calibration taking an appropriate wavelength step (`WFUNCTION`). Then correct for air mass (`EXTINCTION`) and normalize to the unit exposure time. The command `FLUX` will transform the relative fluxes into absolute values (for the standard stars in the IHAP tables, in units of 10^{-16} erg cm^{-2} s^{-1} Å^{-1}). A smooth curve can then be fitted to the points in the internal table created by `FLUX`, using the commands `TSPLINE` or `TPOLY`. The file containing the response curve will be created by using the command `TRESPONSE`. The response curve and also the object spectrum should be normalized to the unit exposure time. An example of the resulting response curve is shown in Fig. 6.2.

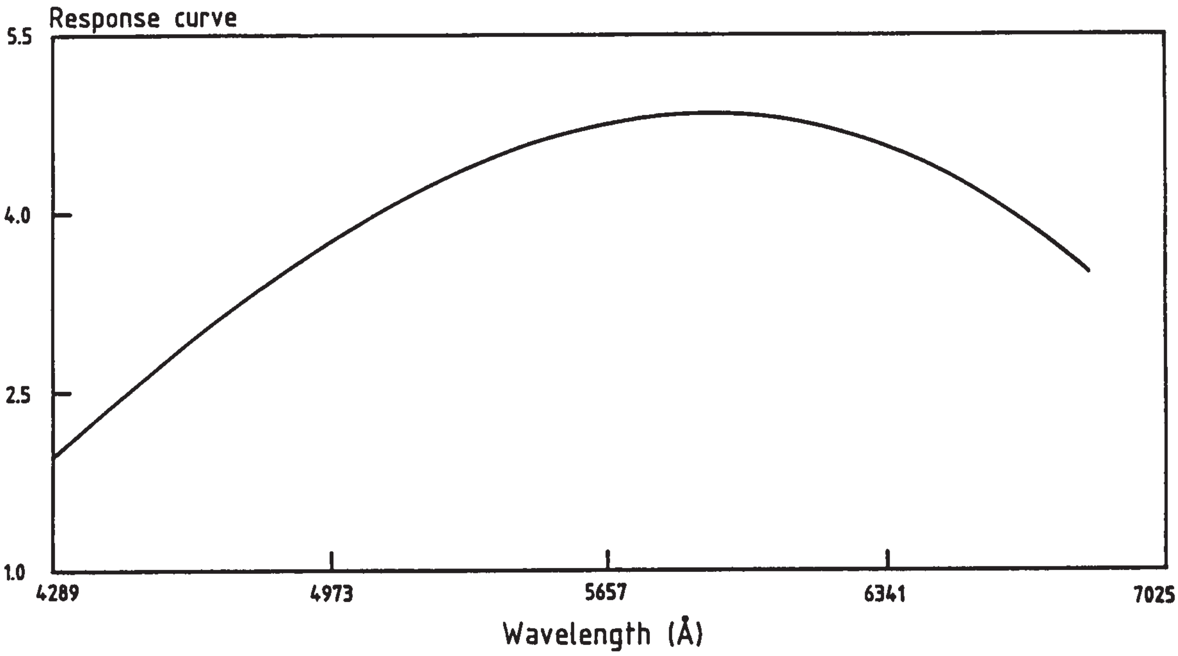


Figure 6.2: Response curve for CCD # 5, grating # 21, 2.2m telescope.

Chapter 7

Remarks for Each Telescope

7.1 3.6m telescope

7.1.1 Acquisition Program

To run, type on the main console: `GICCD`.

7.1.2 He-Ar Exposure

- Turn the He-Ar lamp on manually (on the box beside the console)
- In *Define exposure* form, exposure type: RE, and type the lamp number
- Remote handset OFF in order to avoid moving the Decker

7.1.3 Flat-fields

- For flat-fields using the internal lamp, the procedure is similar to the He-Ar exposure explained above. Close the sky baffle to avoid reflections.
- For flat-fields using the external lamp, open the sky baffle and Cassegrain adaptor shutter

7.2 2.2m Telescope

7.2.1 Acquisition Program

To run, type on the main console: `B&C`.

7.2.2 He-Ar Exposure

- In *Define exposure* form, exposure type: `CL: lamp 4`.

Everything is then automatic.

If you change to the observation field, type:

- `MI, OUT` (i.e. mirror out)
- `LA, OFF` (i.e. lamp off)

7.2.3 Flat-fields

- For an internal lamp flat field, the procedure is similar to a Calibration Exposure, `CL: lamp 2`.
- For an external lamp, use Regular Exposure, `RE: lamp 0`.

7.3 1.52m Telescope

7.3.1 Pointing Limitation

At the 1.52m ESO telescope a severe limitation for pointing is imposed by the northern pillar. For declinations $\delta \leq -45°$, it is impossible to observe more than 30 minutes before the meridian when the telescope is on the east side of the polar axis and more than 30 minutes after the meridian when the telescope is on the west side. The telescope control software will prevent this. For $\delta \leq -45°$ observe on the *west* side for objects before the meridian, and on the *east* side for objects after the meridian. Changing the telescope from east to west and vice versa is not recommended during the night, because it is both delicate and time consuming.

7.3.2 Acquisition Program

To run, type on the main console: `GICCD`.

7.3.3 Calibration Exposures

A new calibration lamp system was installed at the 1.52 m telescope in November 1988. This allows remote selection and switching of calibration lamps. A neutral density wheel is also remotely controllable. All these functions are controlled from a rack located on top of the observing desk.

He-Ar Exposure

- He-Ar LAMP: on
- LAMP-SELECT MIRROR: He-Ar
- CALIBRATION MIRROR: in
- Choose the density
- Check both Hartmann shutters are out
- In *Define exposure* form, exposure type: CL or RE
- After exposures, do not forget to turn off the lamp and remove the CALIBRATION MIRROR.

Flat-field with Internal Lamp

- Proceed as above (except select and turn on the flat-field lamp HAL-WHITE)

Flat-field with External Lamp

- Proceed as a science exposure:
- Telescope mirror open
- Hartmann shutters out (manually)
- He-Ar LAMP: OFF
- HAL-WHITE LAMP: OFF
- LAMP-SELECT MIRROR: unimportant
- CALIBRATION MIRROR: out
- Telescope pointing to the white screen
- Exposure type: RE or FF

Dark Exposure

- Hartmann shutters in (manually)
- Lamps switched off
- Telescope mirror closed

- Light in the dome off
- CALIBRATION MIRROR: OUT
- LAMP-SELECT MIRROR: unimportant
- Exposure type: DK

Note

Do not forget to turn the calibration lamps off at the end of the night.

Appendix A

Calculation of the Spectral Resolution

Here we present the formulae for deriving the spectral resolution.

λ: central wavelength, Å
n: number of grooves, mm^{-1}
m: diffraction order
ϕ: grating configuration angle (see Fig. 2.1.)
θ: grating angle
w: entrance slit-width, μm
w': projected slit-width, μm
f_1: collimator focal length, mm
f_2: camera focal length, mm
D: dispersion, Å mm^{-1}
R_s: theoretical spectrograph resolution, Å (without detector)
γ: transversal magnification factor = f_2/f_1

$$\theta = sin^{-1}\left(\frac{nm\lambda}{2\times10^7\cos(\phi/2)}\right) \qquad w' = w\left(\frac{f_2}{f_1}\right)\left(\frac{\cos(\theta+\phi/2)}{\cos(\theta-\phi/2)}\right)$$

$$D = \left(\frac{10^7\cos(\theta-\phi/2)}{nmf_2}\right) \qquad R_s = Dw' = \left(\frac{10^4 w\cos(\theta+\phi/2)}{nmf_1}\right)$$

The effective CCD spectral resolution is the convolution of R_s with the detector pixel size. With suitable detector sizes, the spectrum may be sufficiently sampled to avoid spectral information distortion (eg. line profile distortions). The *common* sampling criterion is R_s = 2 pixels (ie. Nyquist criterion). The *actual* sampling criterion to be used will be examined in a future version of this manual.

Appendix B

List of Gratings

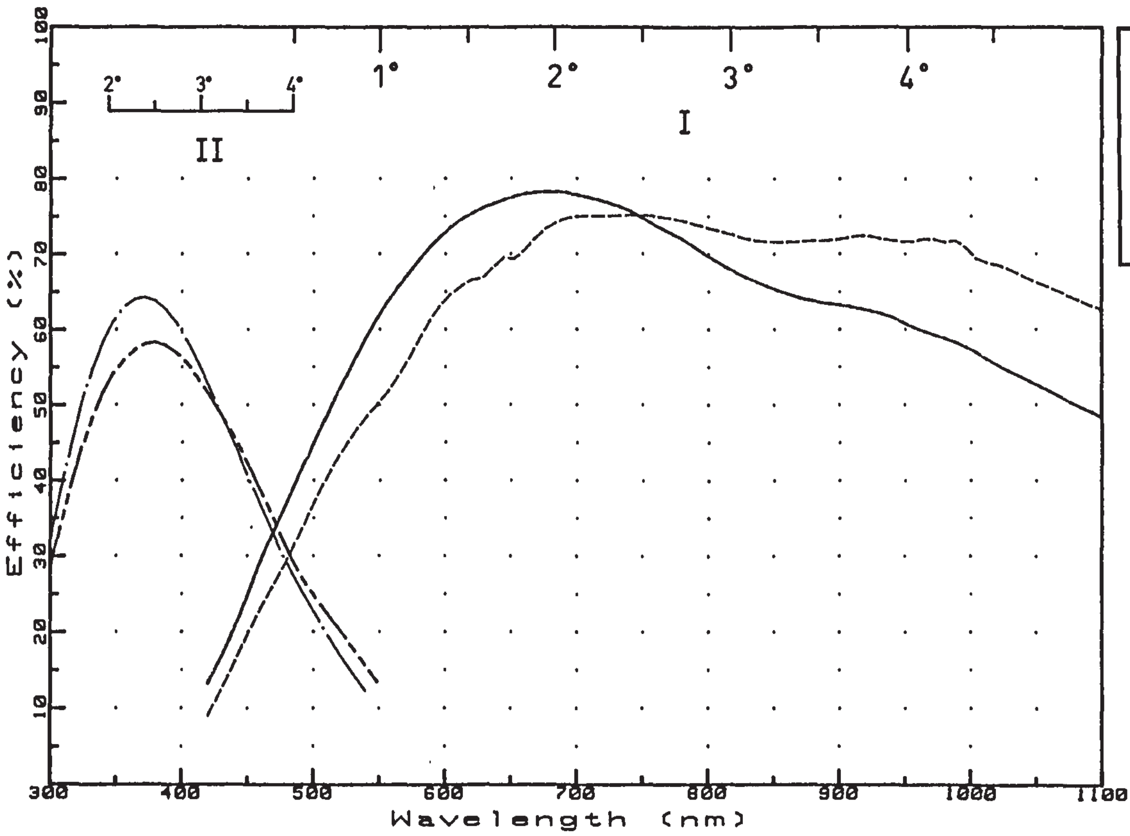
Grating #	*Grooves* mm^{-1}	*Blaze angle**	*Blaze wavelength* *, Å	*Dispersion** *Order*	*Å* mm^{-1}
13	150	2°09'	4550	1	450
1	225	5°20'	7236	1	298
			3618	2	149
2, 15	300	4°18'	4550	1	224
9, 18	300	8°38'	9100	1	228
			4550	2	114
8, 24	400	4°30'	3640	1	171
16, 21	400	6°54'	5400	1	172
3, 17	400	9°44'	7700	1	173
			3852	2	86.5
14	400	13°54'	12000	1	172
7, 23	600	8°38'	4550	1	114
4, 6	600	13°00'	6825	1	116
			3412	2	58
10, 19	600	17°27'	9100	1	118
			4550	2	59
5	900	21°10'	7236	1	78
			3618	2	39
12, 22	1200	26°45'	6825	1	59.5
			3412	2	29.8
11, 20	1200	36°52'	9100	1	58
			4550	2	29
25	400	6°30'	5150	1	172
26	1200	22°12'	5730	1	59.5
27	600	11°21'	5970	1	114
28	600	17°27'	9096	1	114
			4548	2	58
29, 30	600	5°10'	3000	1	114
31	1200	10°22'	3000	1	60

* These are approximate values differing within 5% of the effective values depending on the B & C configuration used at different telescopes (c.f. Appendix A). The dispersions must be multiplied by 1.13 for the new camera at the 1.52 m telescope.

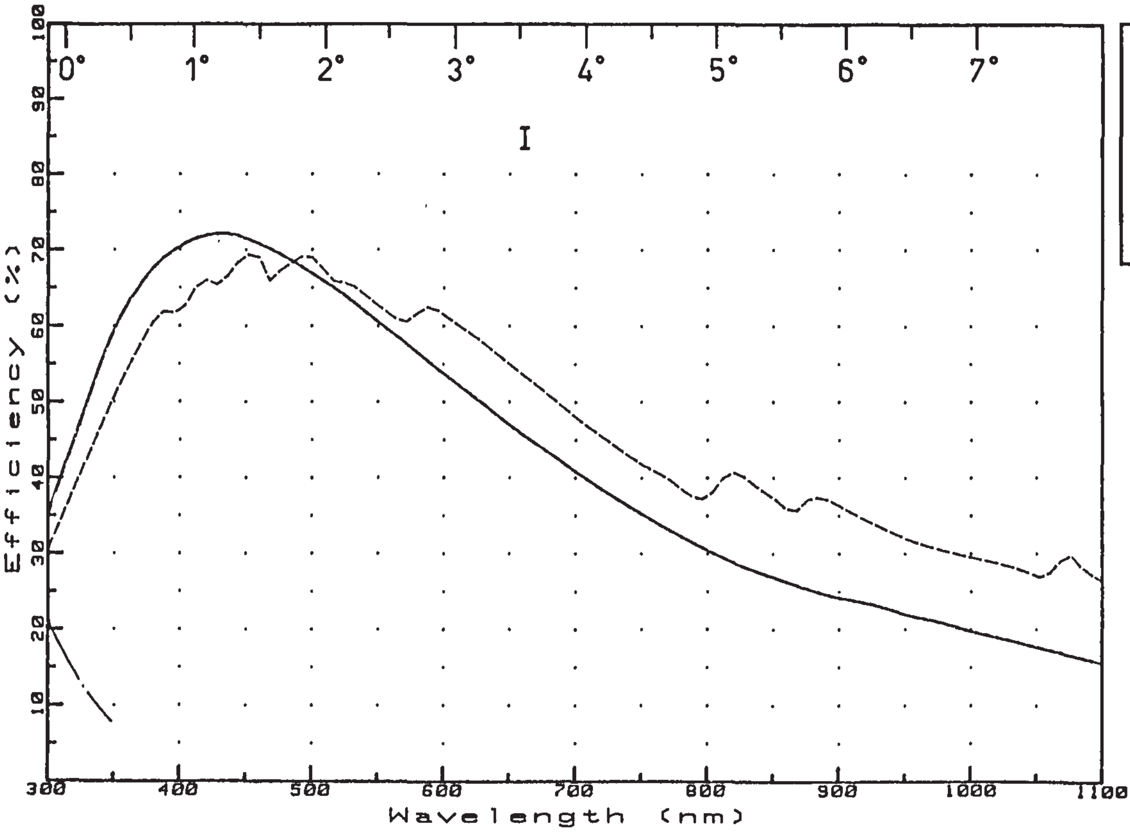
Appendix C

Grating Efficiency Curves

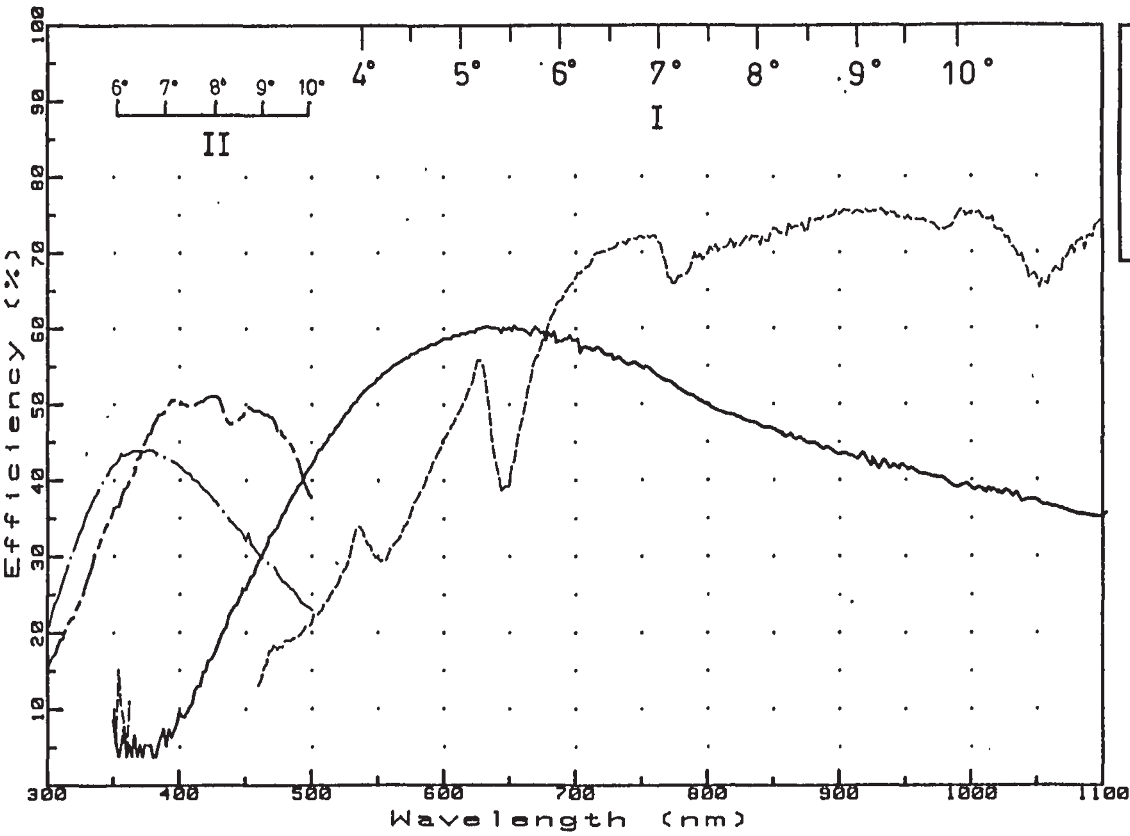
The following set of plots show the efficiency of the gratings as a function of wavelength for linearly polarized light parallel and perpendicular to the grooves as measured in the ESO optical laboratory in Garching. The solid line shows the efficiency curves for light polarized parallel to the grooves and the dashed lines are for light polarized perpendicular to the grooves. The numbers at the top of each figure show the grating angles as a function of wavelength and order. The dispersion values for the 1.52m spectrograph should be multiplied by 1.13 due to the different focal length camera.



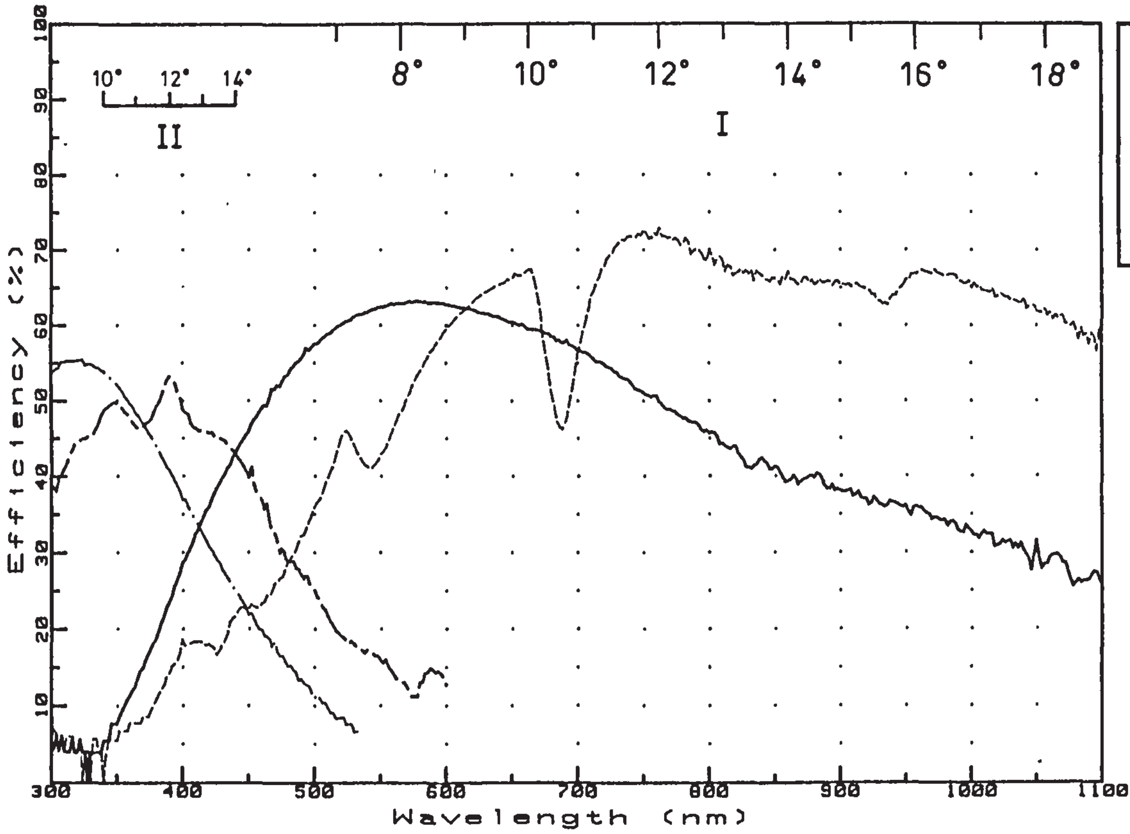
Grating 1
225 gr mm^{-1}
300 Å mm^{-1}
θ=5^{0}2$'$



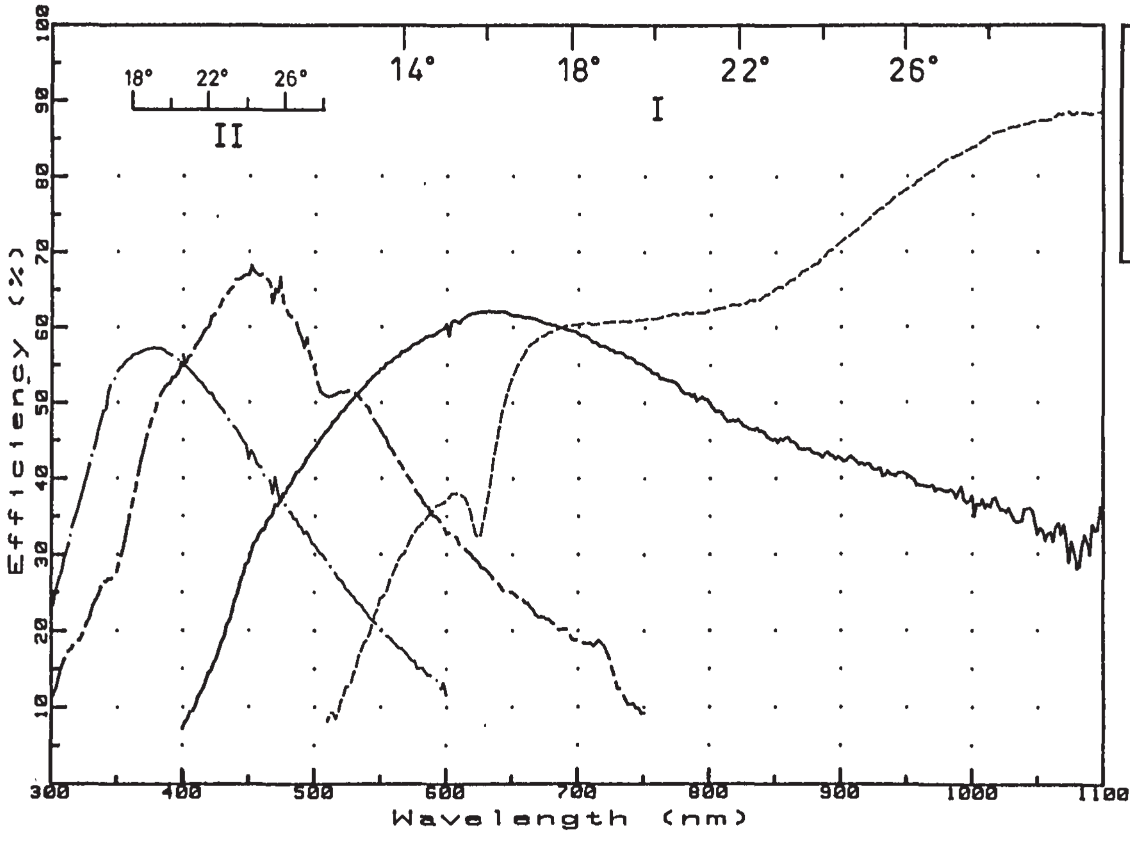
Grating 2
300 gr mm^{-1}
224 Å mm^{-1}
θ=4^{0}18$'$



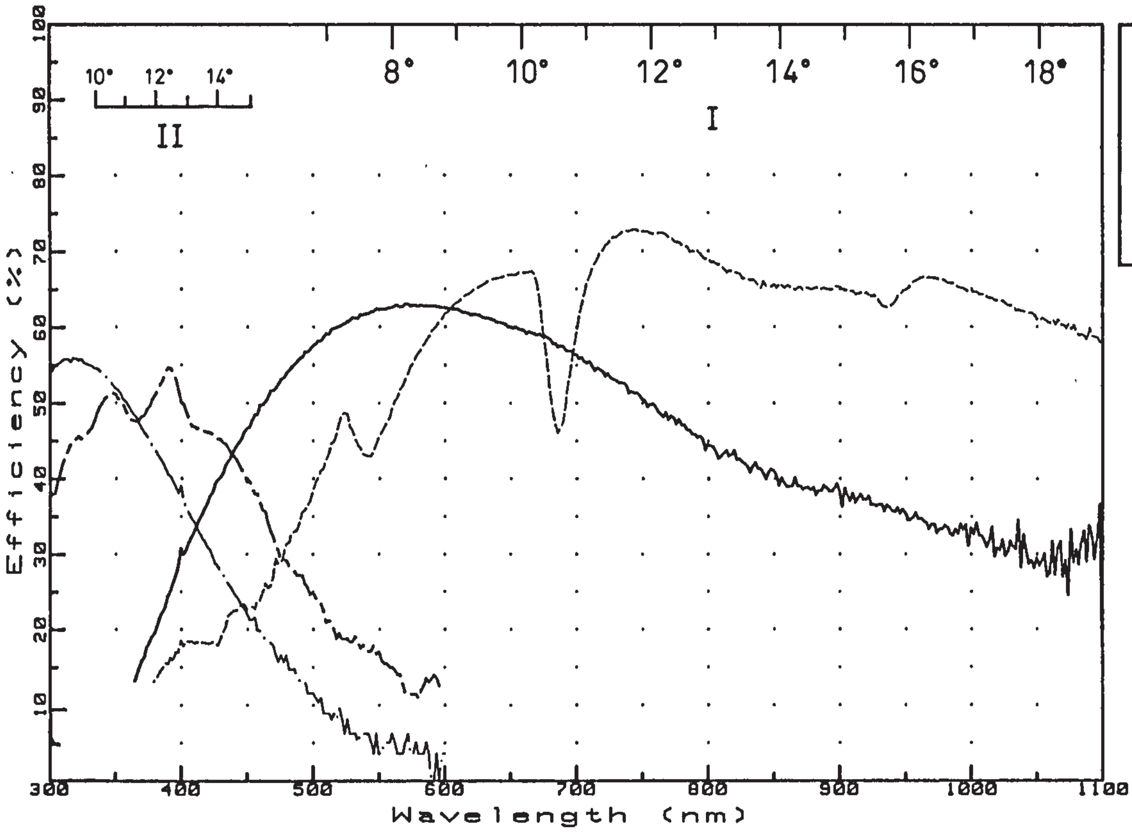
Grating 3
400 gr mm^{-1}
173 Å mm^{-1}
θ=9^{0}44$'$



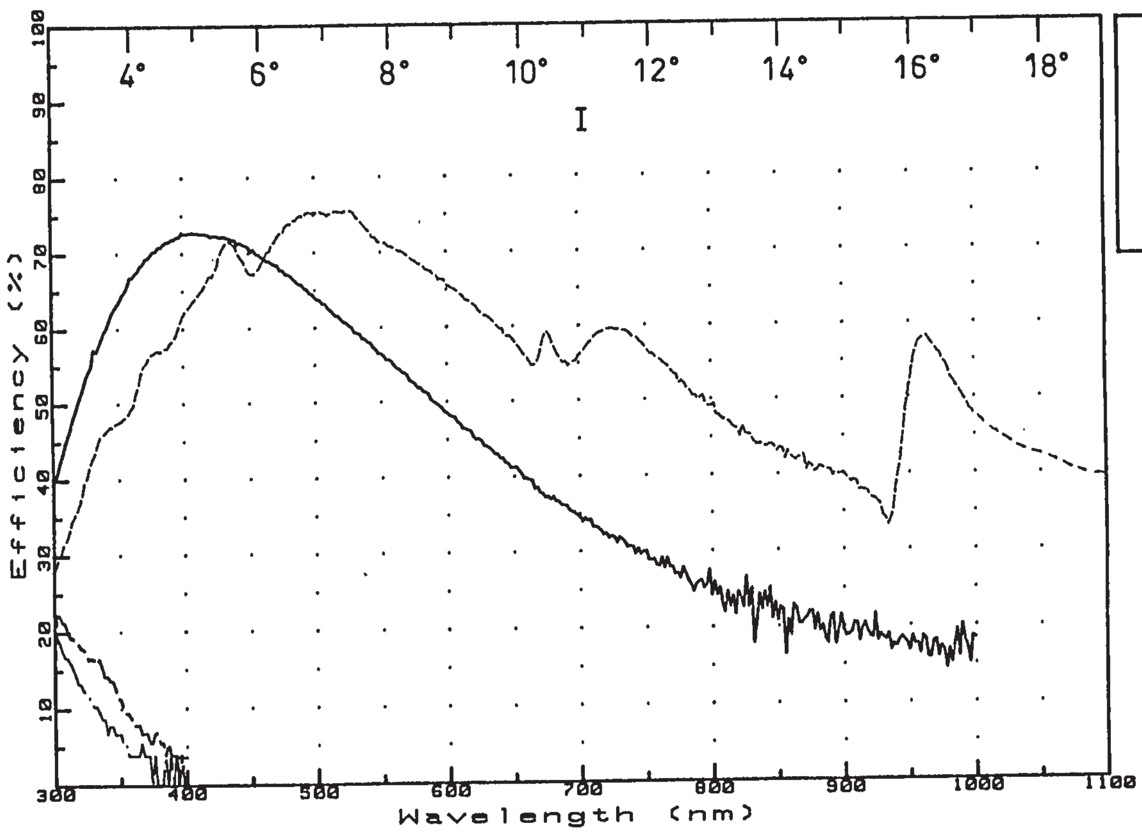
Grating 4
600 gr mm^{-1}
116 Å mm^{-1}
θ=13^{0}0$'$



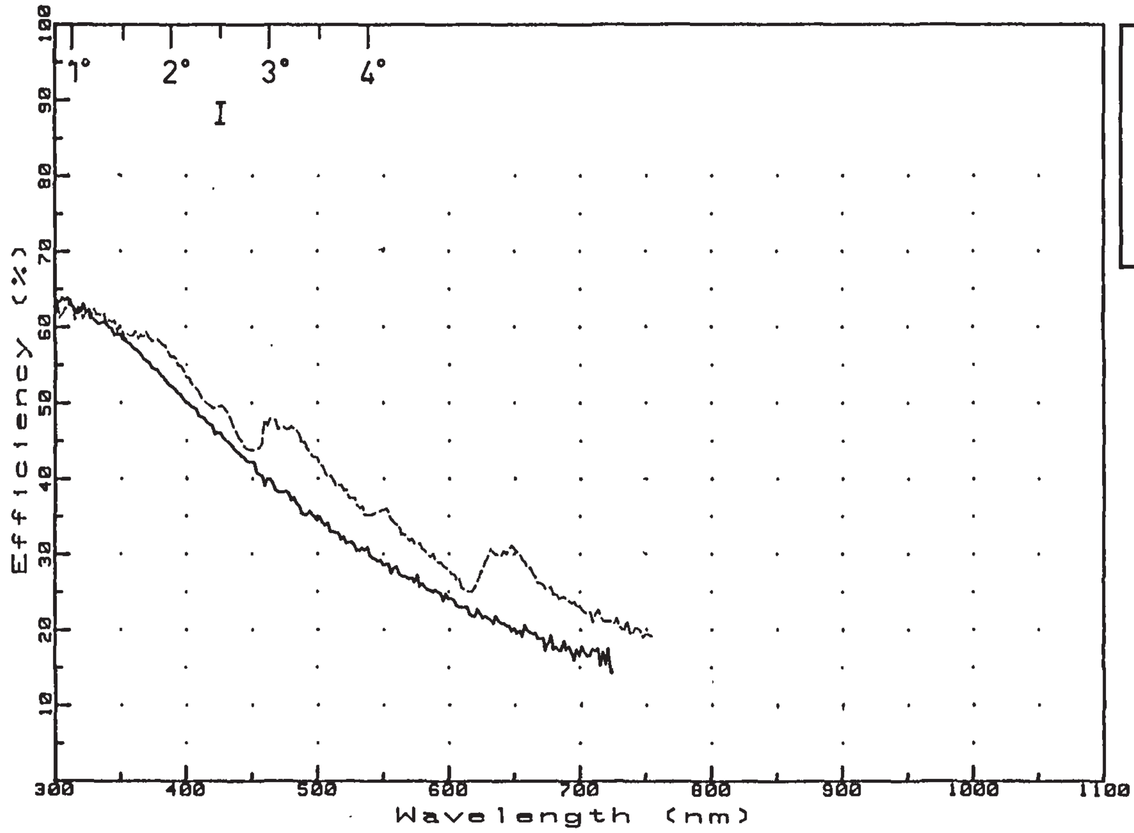
Grating 5
900 gr mm^{-1}
78.6 Å mm^{-1}
θ=21^{0}10$'$



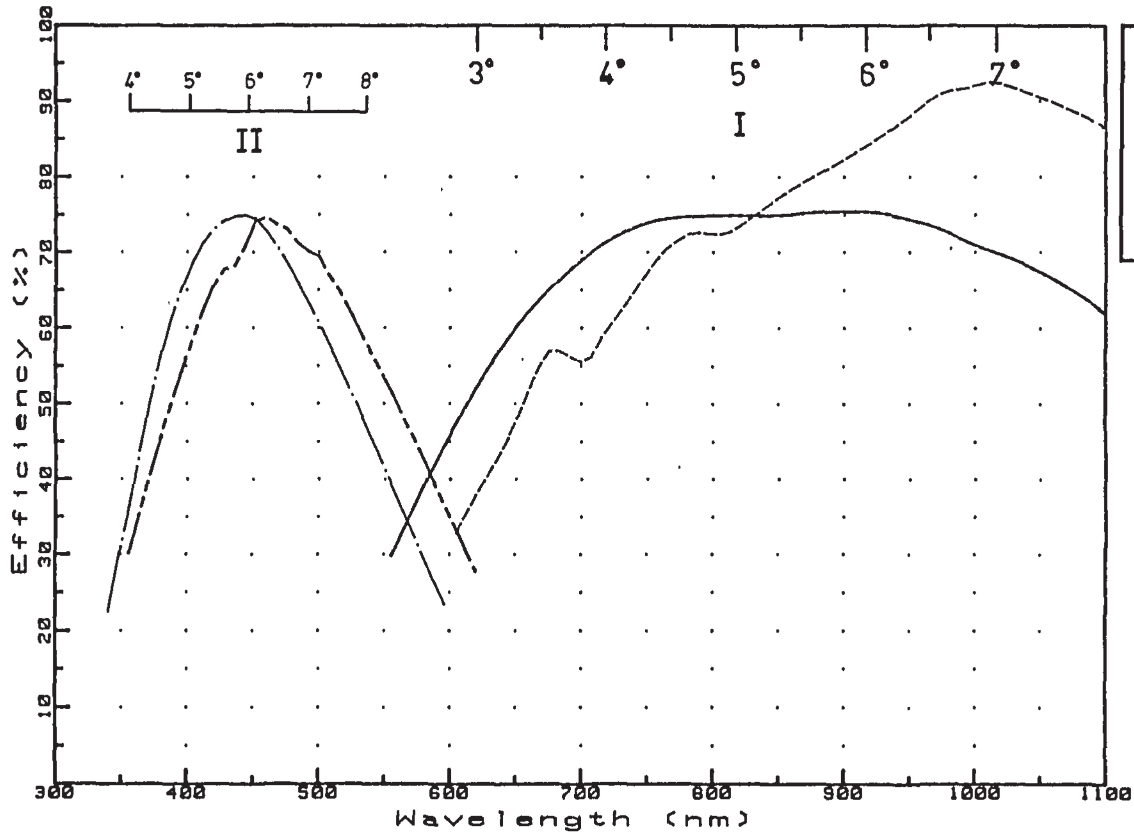
Grating 6
600 gr mm^{-1}
116 Å mm^{-1}
θ=13^{0}0′



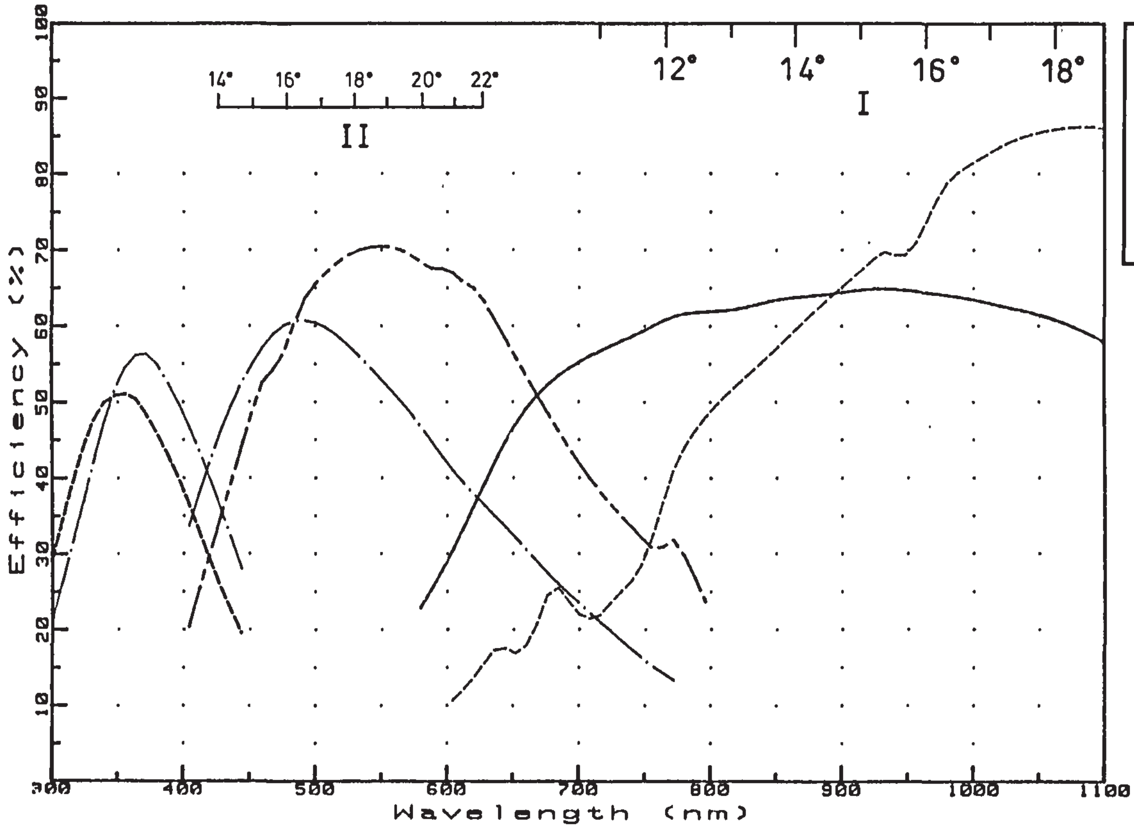
Grating 7
600 gr mm^{-1}
114 Å mm^{-1}
θ=8^{0}38′



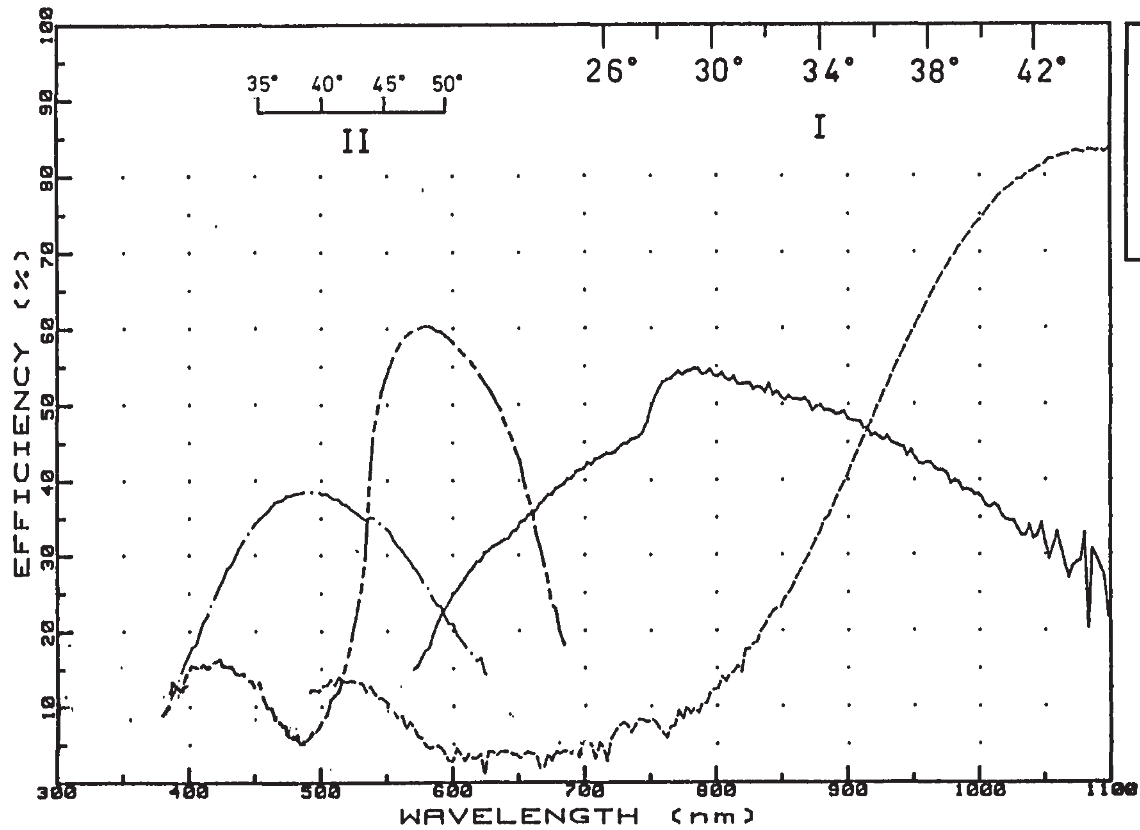
Grating 8
400 gr mm^{-1}
171 Å mm^{-1}
θ=4°30′



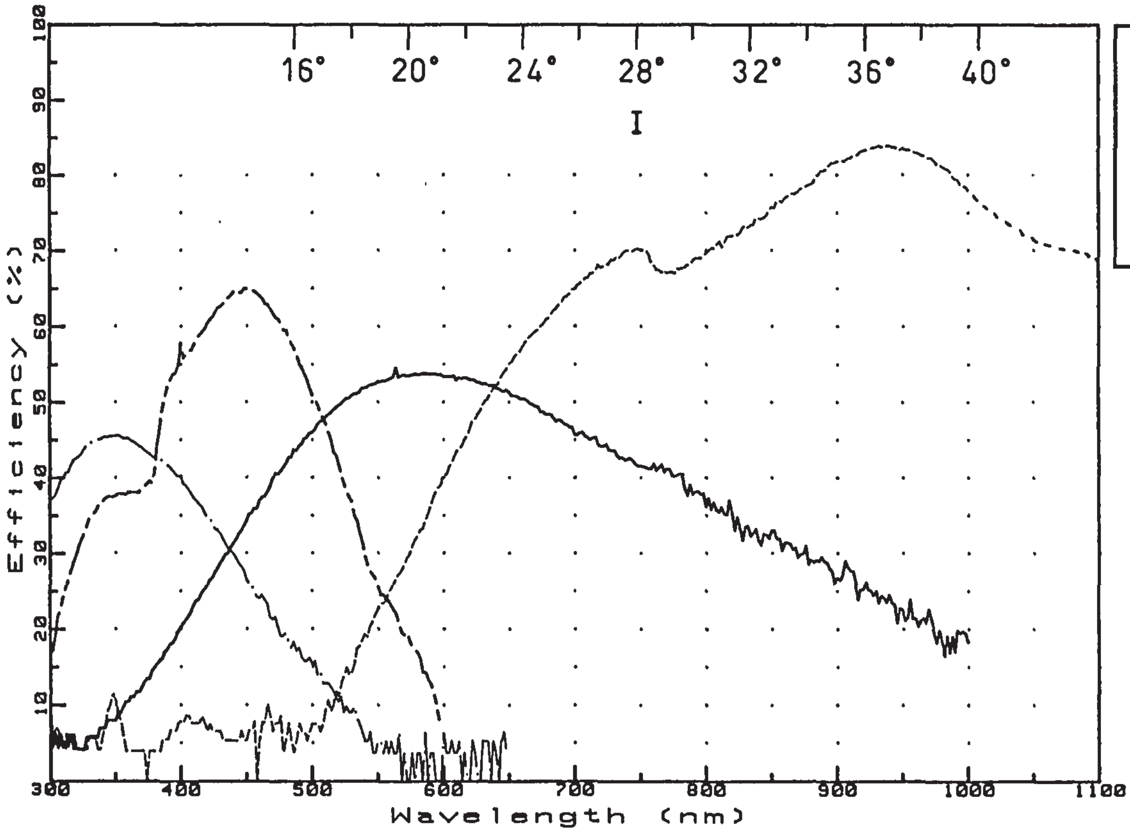
Grating 9
300 gr mm^{-1}
228 Å mm^{-1}
θ=8°38′



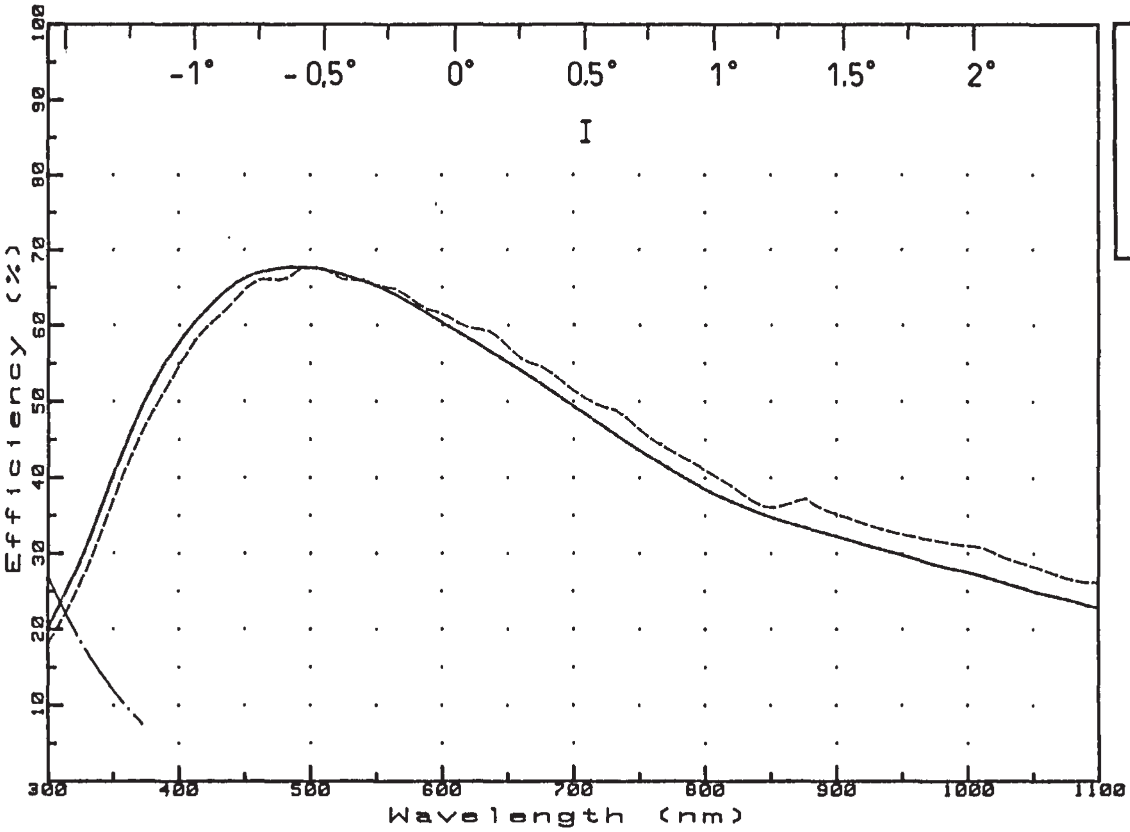
Grating 10
600 gr mm^{-1}
118 Å mm^{-1}
θ=17^{0}27$'$



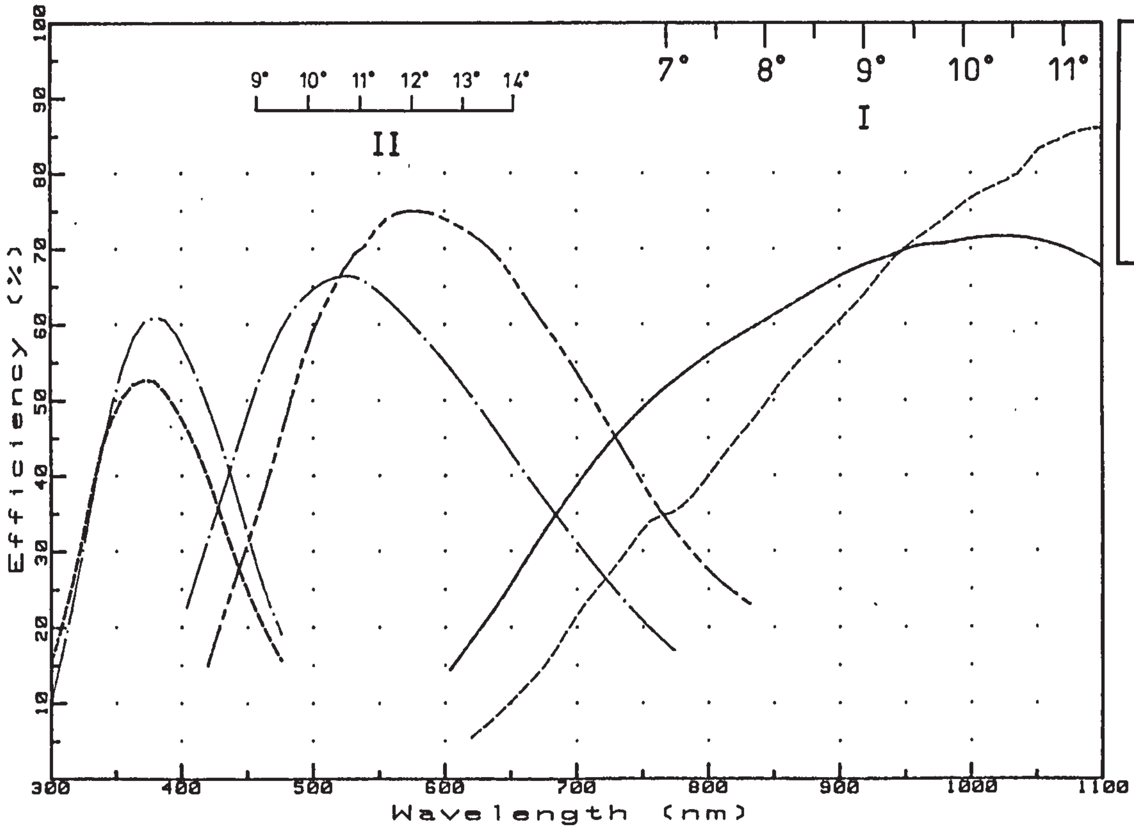
Grating 11
1200 gr mm^{-1}
58 Å mm^{-1}
θ=36^{0}52$'$



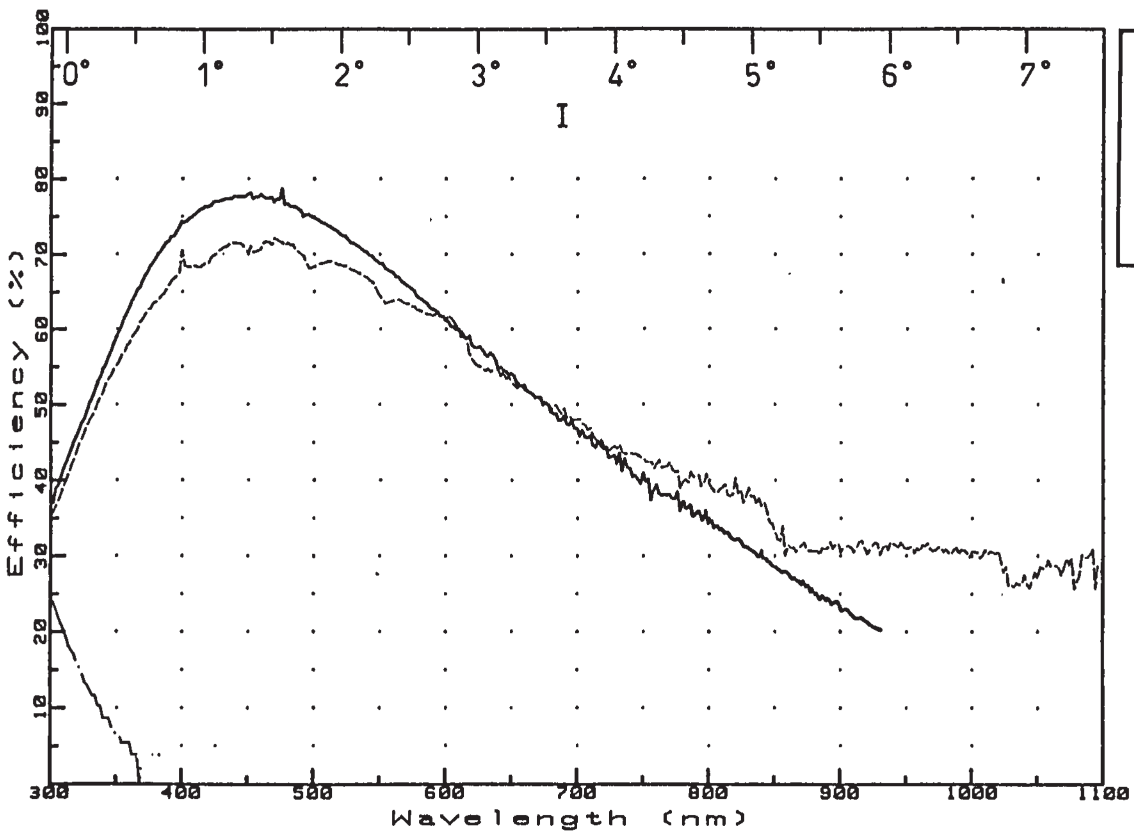
Grating 12
1200 gr mm^{-1}
60 Å mm^{-1}
θ=26^{0}45$'$



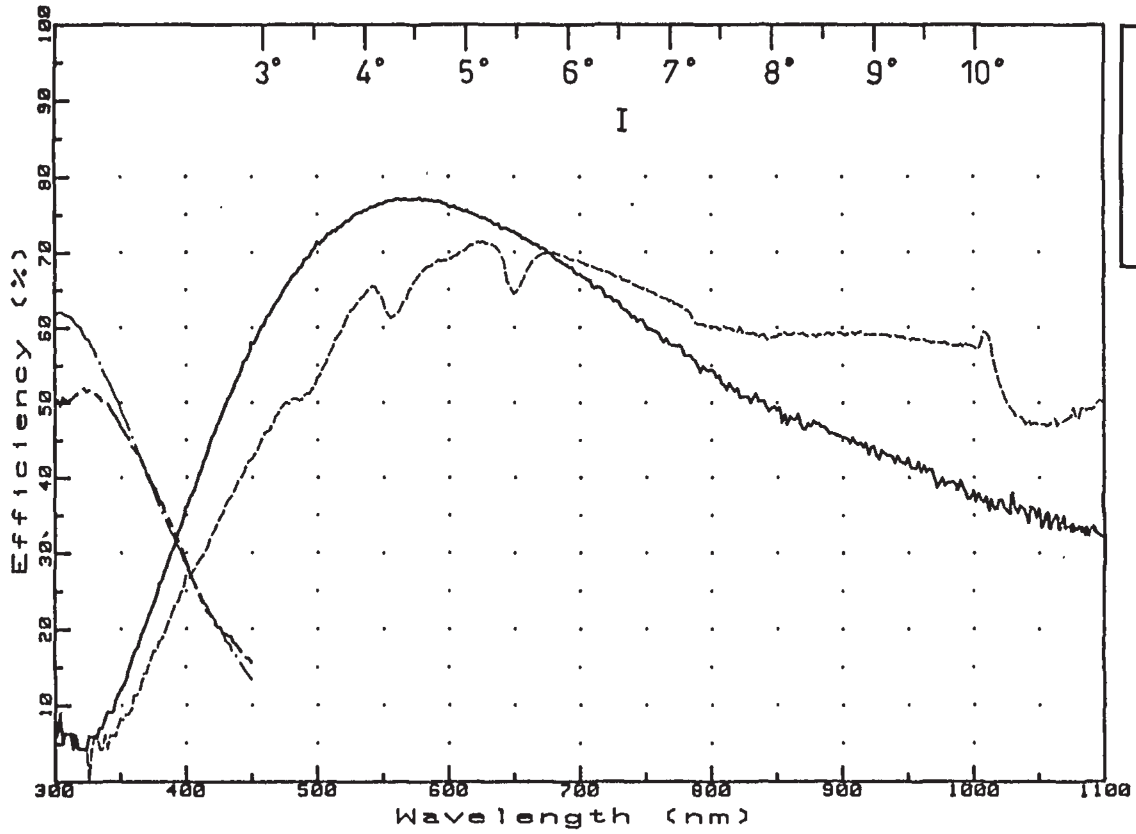
Grating 13
150 gr mm^{-1}
450 Å mm^{-1}
θ=2^{0}9$'$



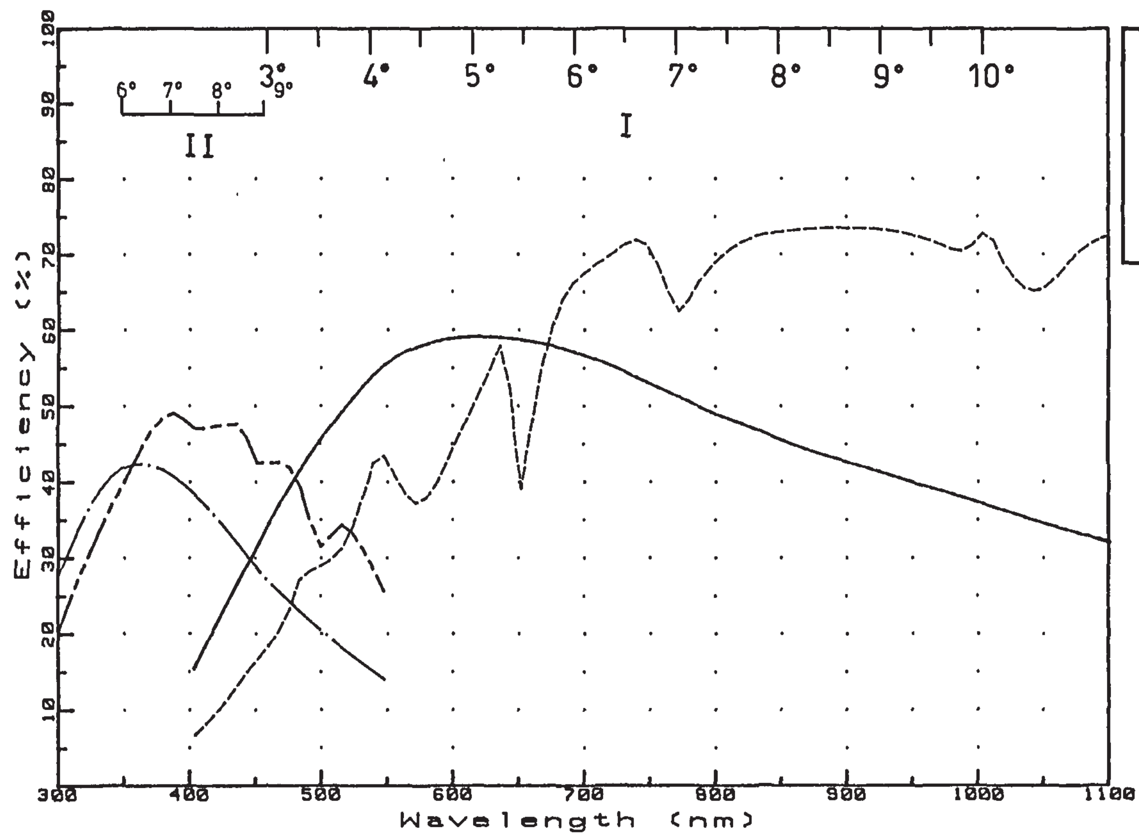
Grating 14
400 gr mm^{-1}
172 Å mm^{-1}
θ=$13^0 54'$



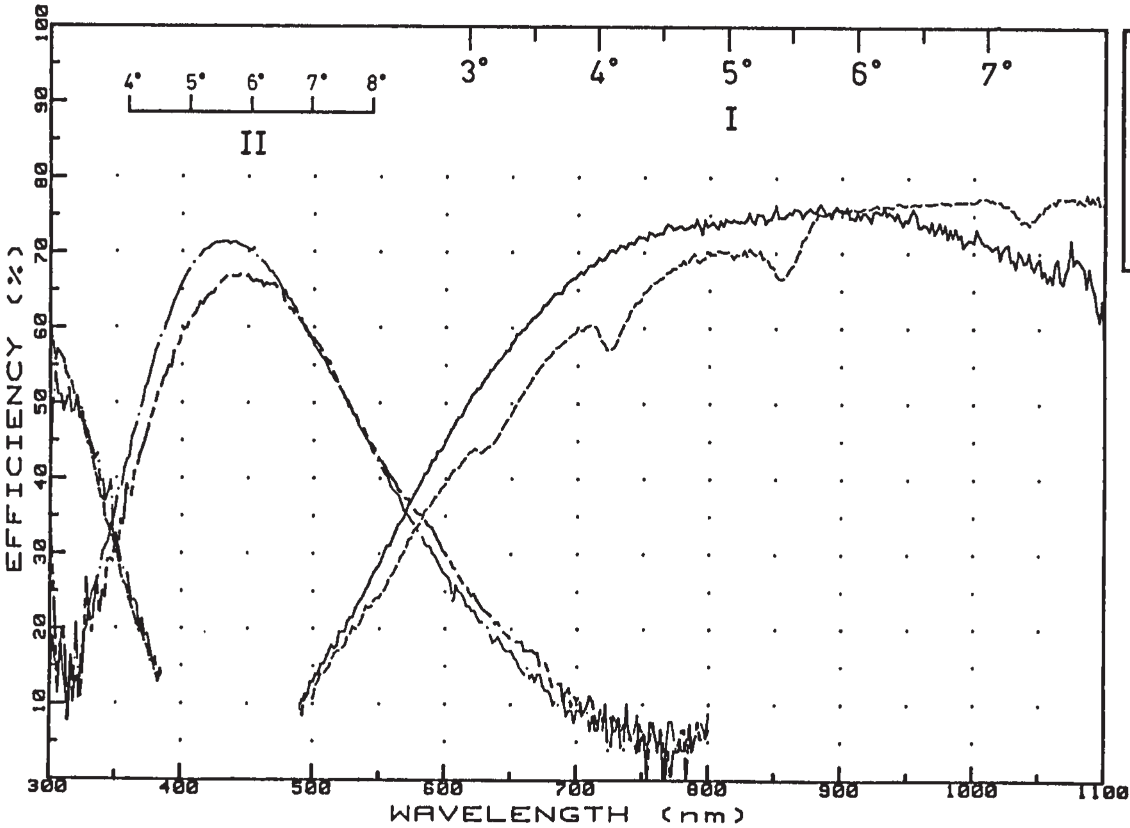
Grating 15
300 gr mm^{-1}
224 Å mm^{-1}
θ=$4^0 18'$



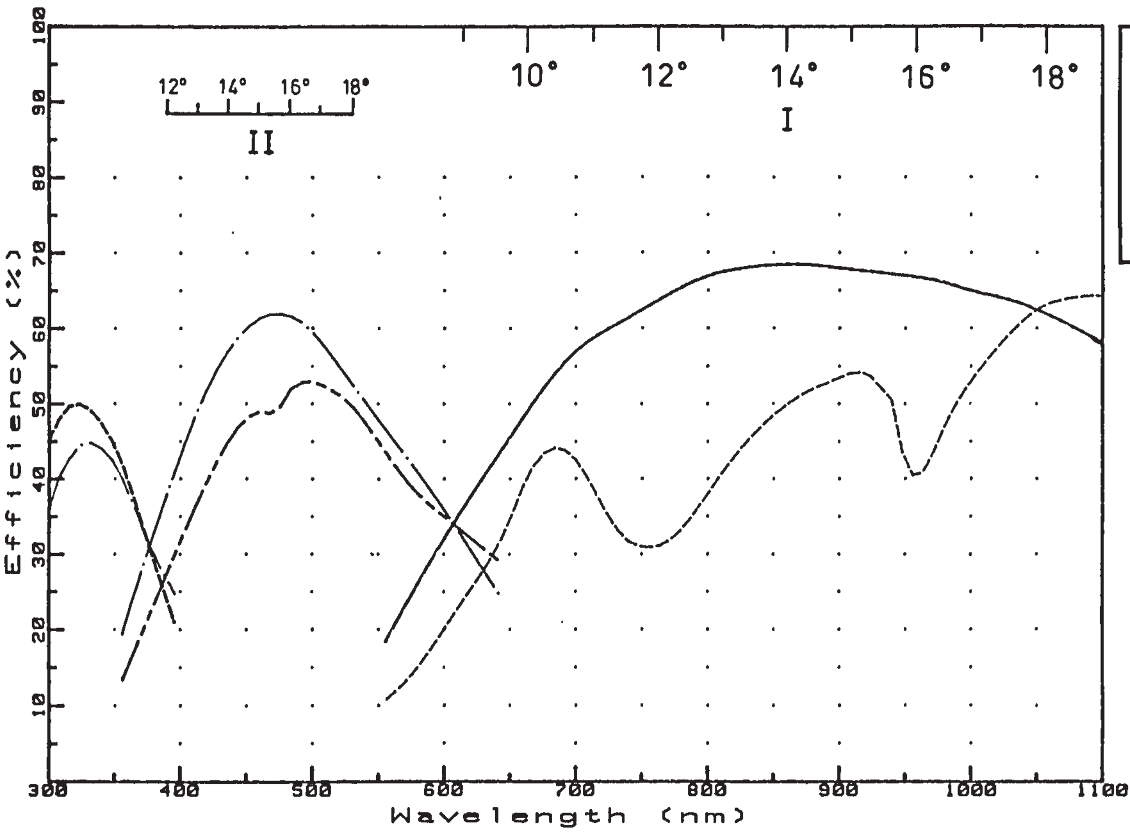
Grating 16
400 gr mm^{-1}
172 Å mm^{-1}
θ=6^{0}54′



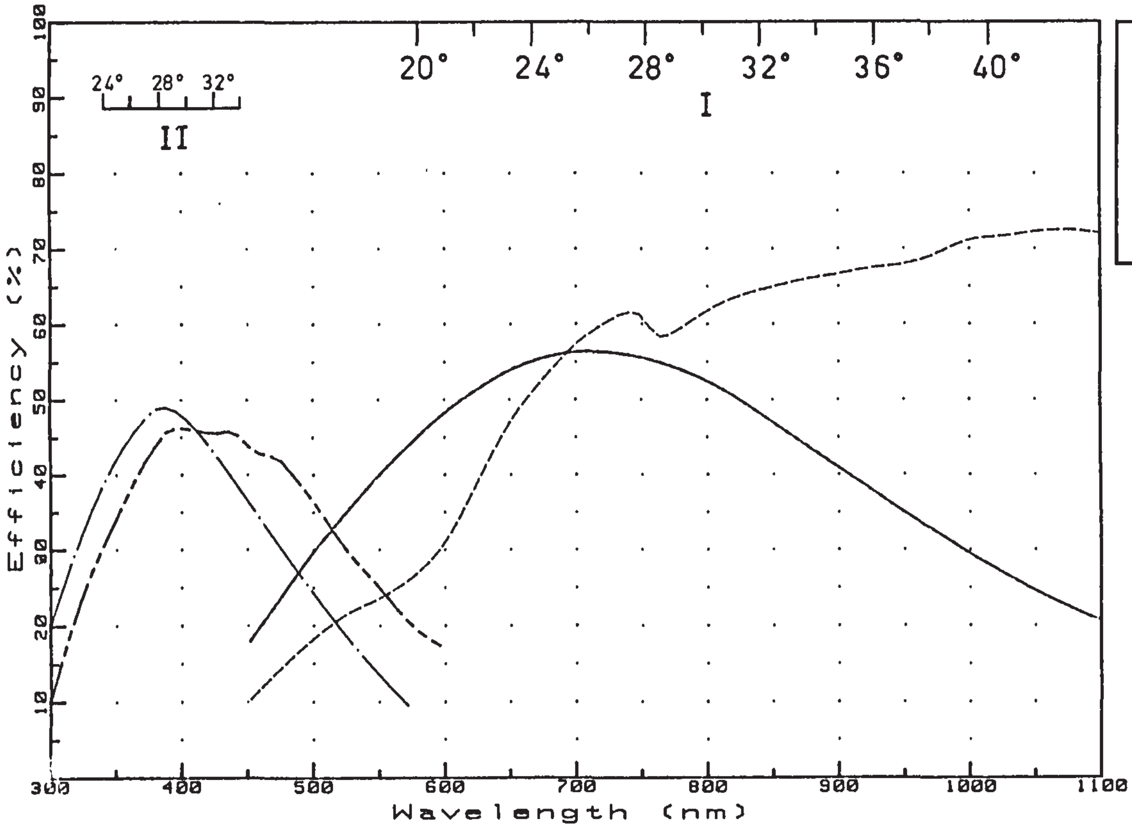
Grating 17
400 gr mm^{-1}
173 Å mm^{-1}
θ=9^{0}44′



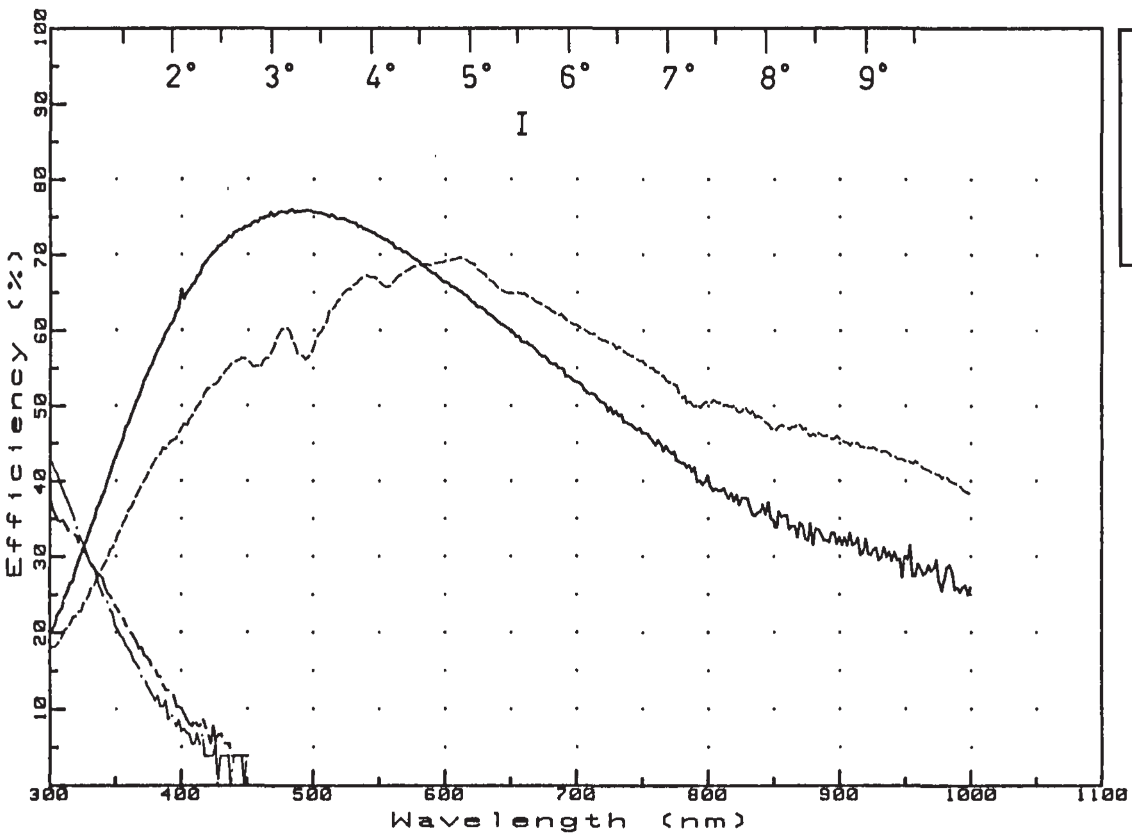
Grating 18
300 gr mm^{-1}
228 Å mm^{-1}
θ=8^{0}38$'$



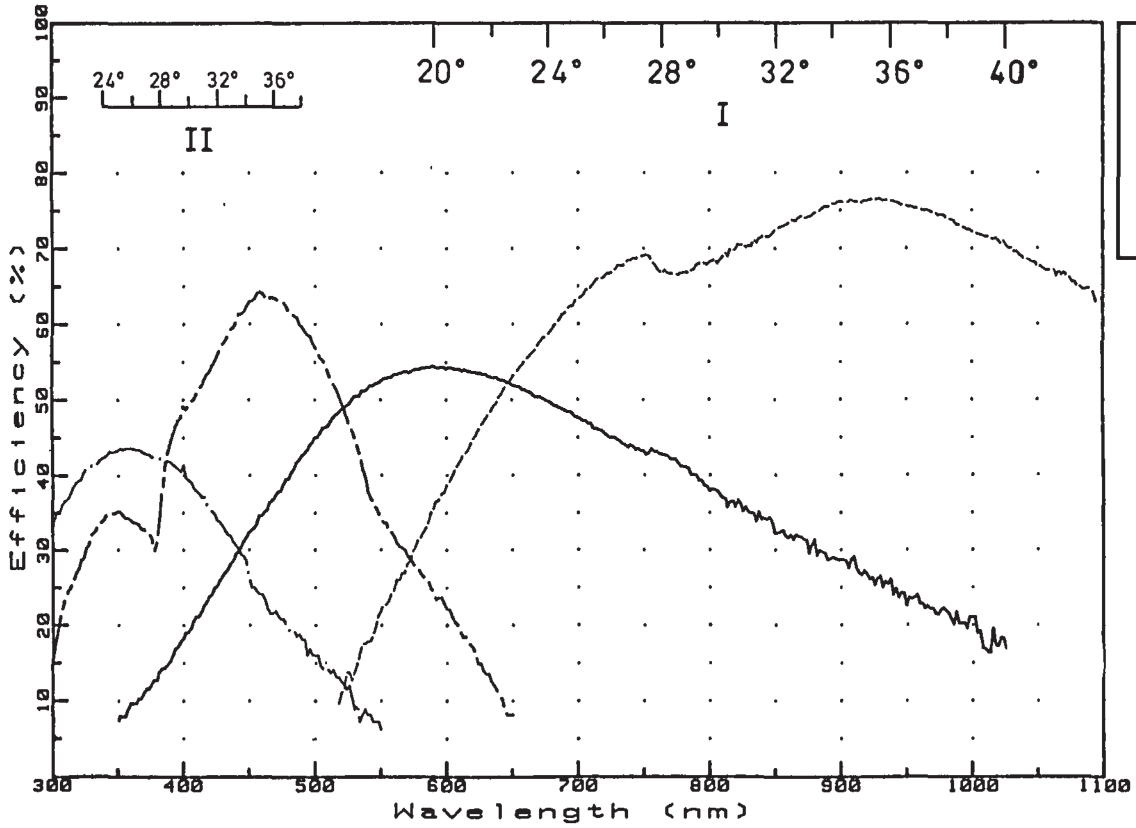
Grating 19
600 gr mm^{-1}
118 Å mm^{-1}
θ=17^{0}27$'$



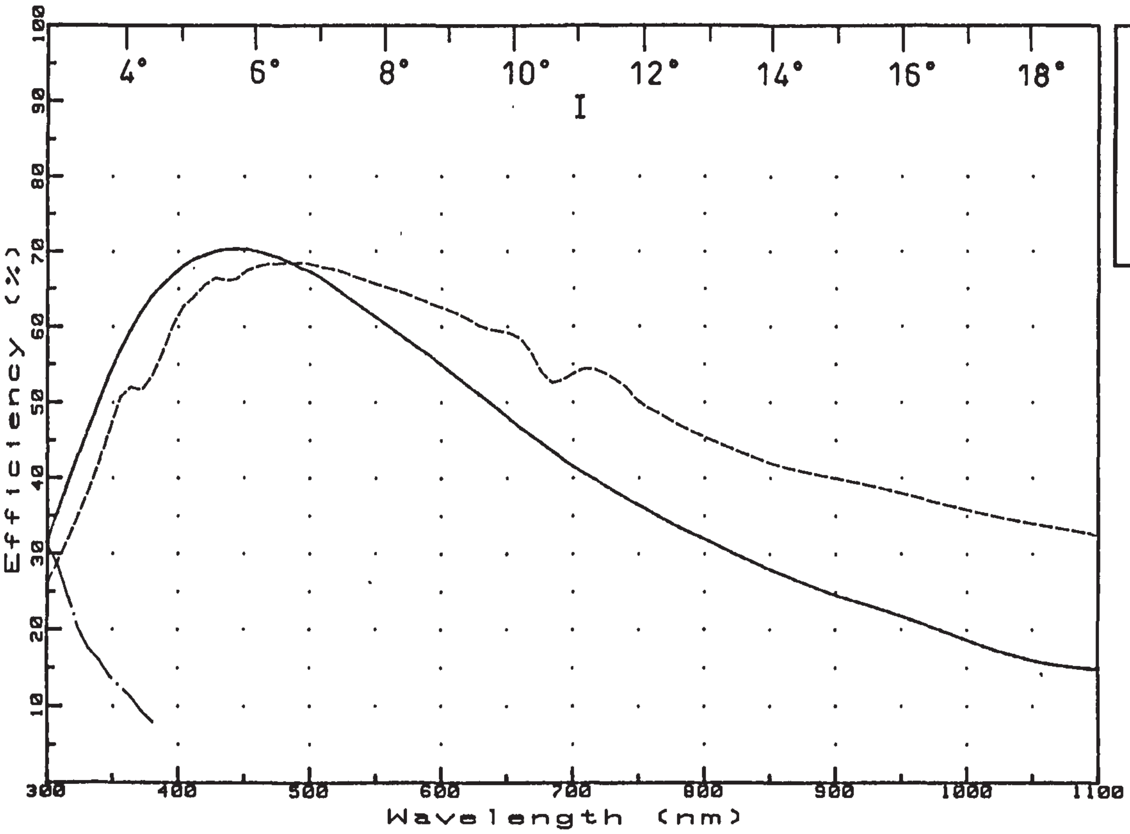
Grating 20
1200 gr mm^{-1}
58 Å mm^{-1}
θ=36^{0}52$'$



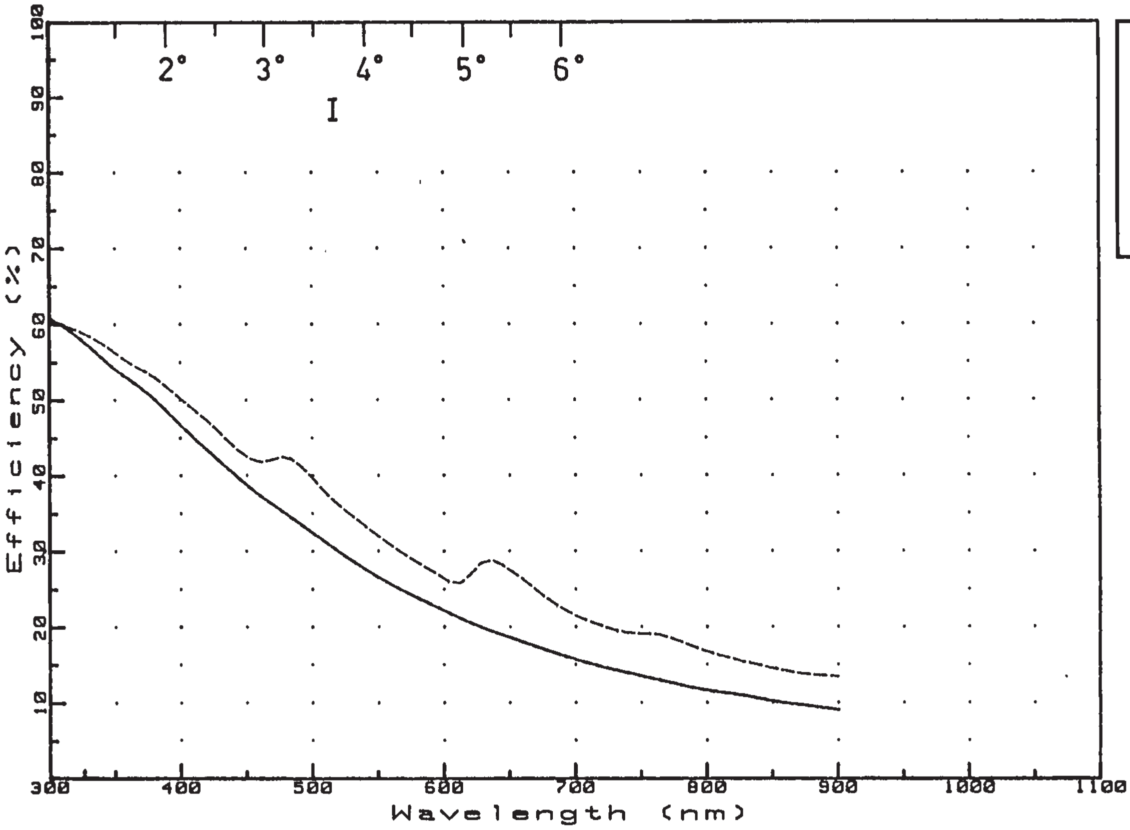
Grating 21
400 gr mm^{-1}
172 Å mm^{-1}
θ=6^{0}54$'$



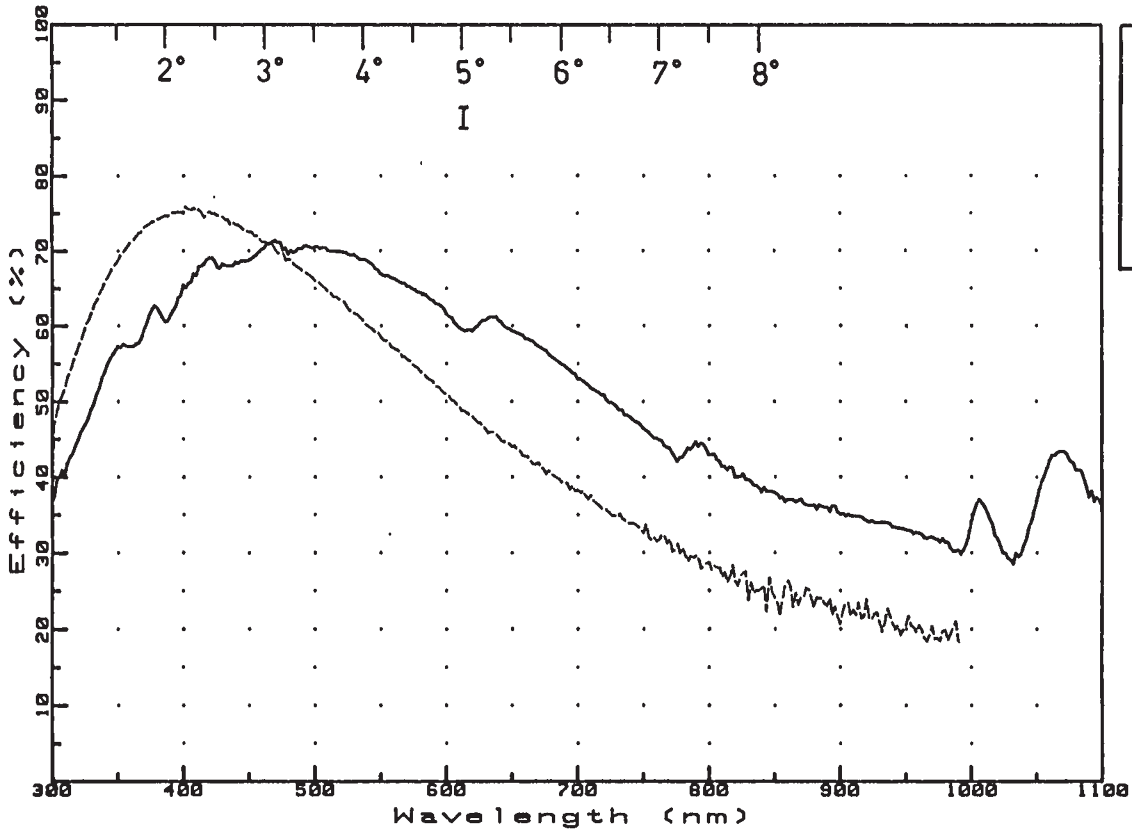
Grating 22
1200 gr mm^{-1}
60 Å mm^{-1}
θ=$26^0 145'$



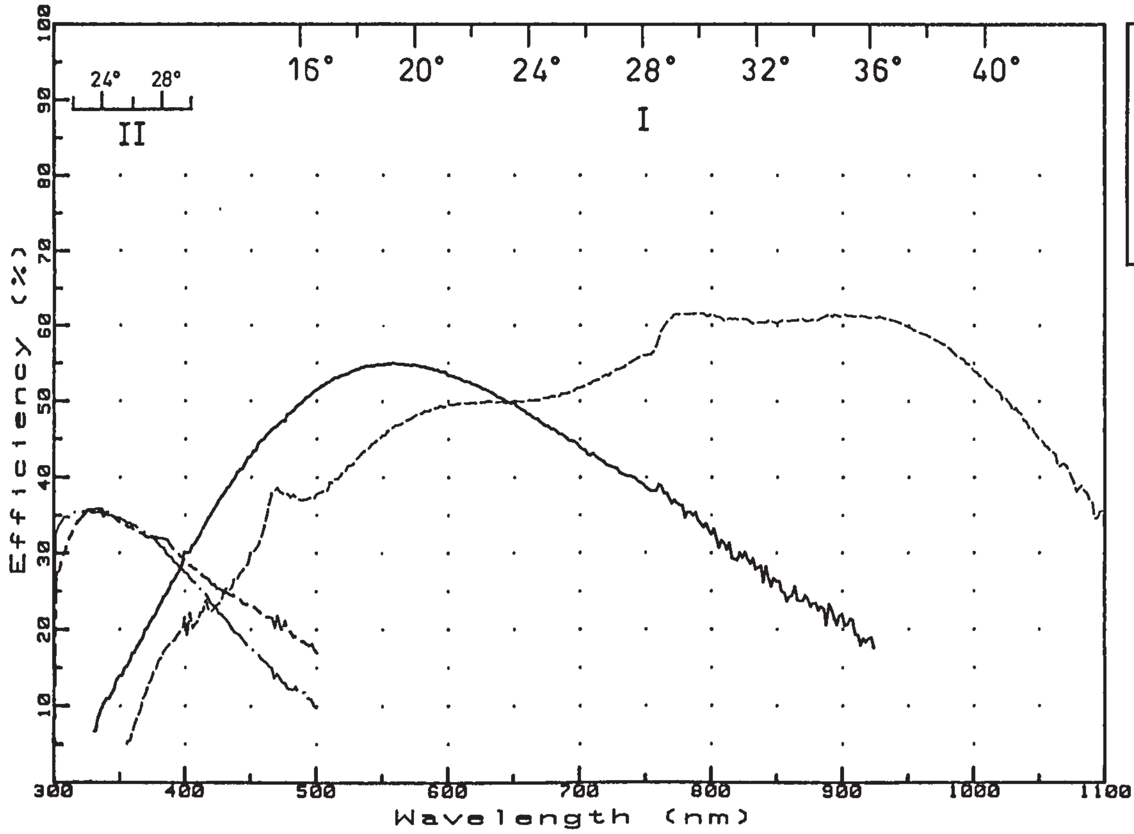
Grating 23
600 gr mm^{-1}
114 Å mm^{-1}
θ=$8^0 38'$



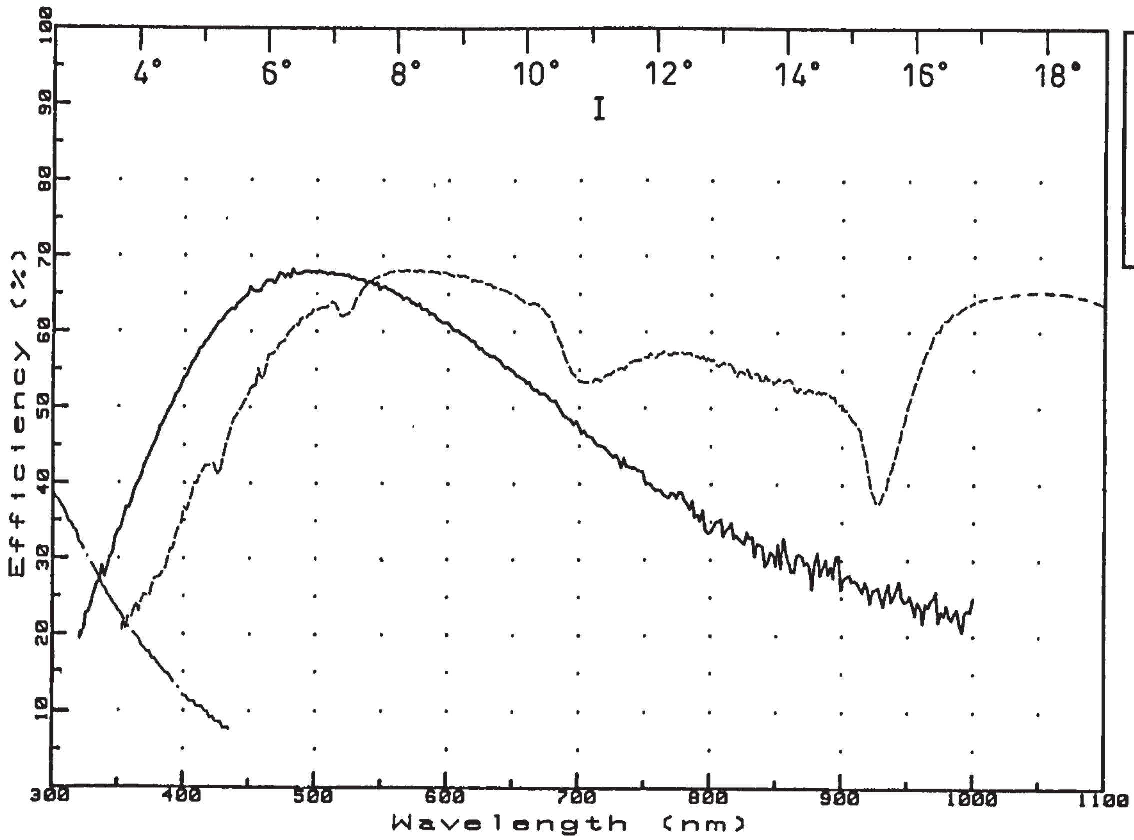
Grating 24
400 gr mm^{-1}
171 Å mm^{-1}
θ=4^{0}30$'$



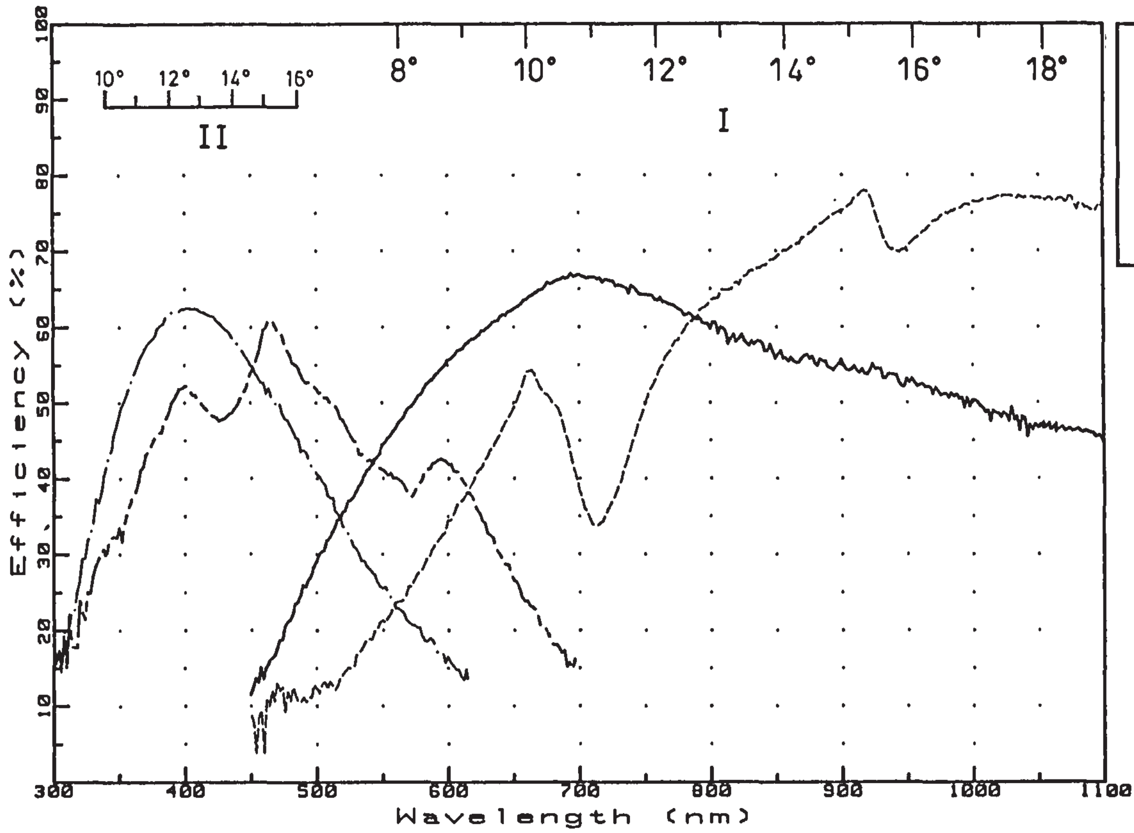
Grating 25
400 gr mm^{-1}
172 Å mm^{-1}
θ=6^{0}30$'$



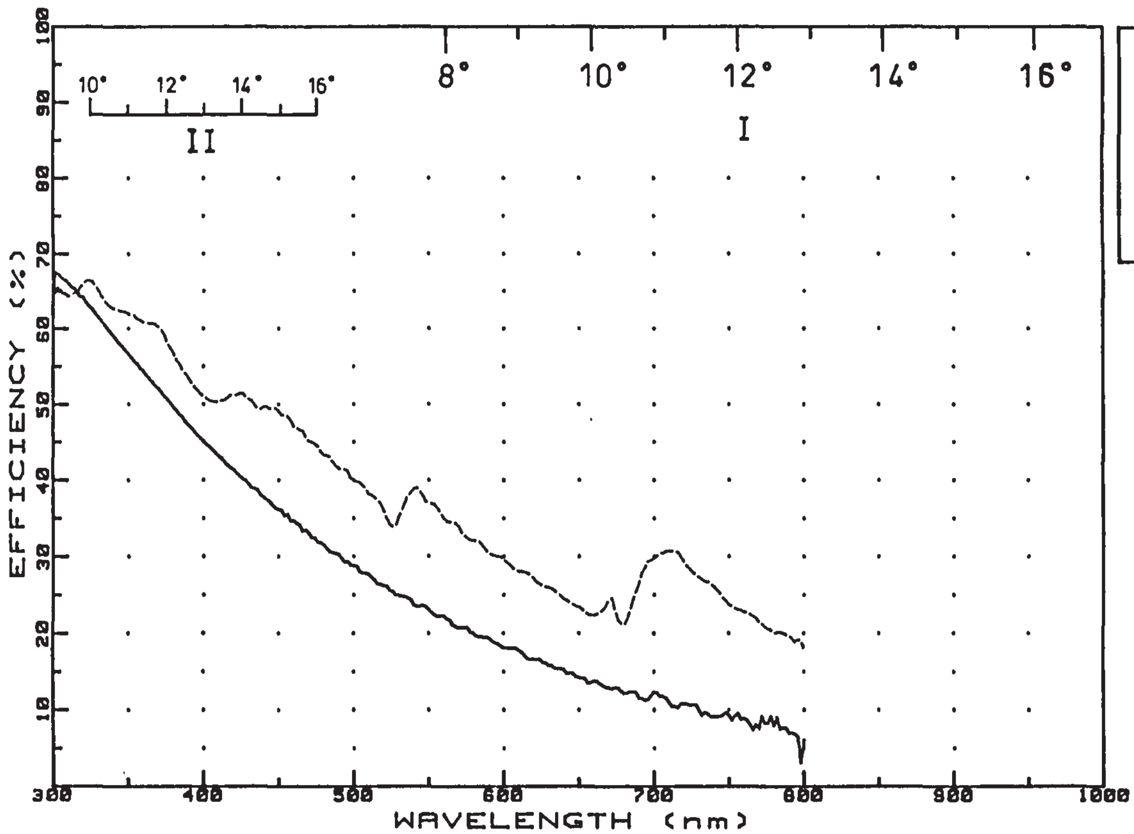
Grating 26
1200 gr mm^{-1}
58 Å mm^{-1}
θ=22^{0}12$'$



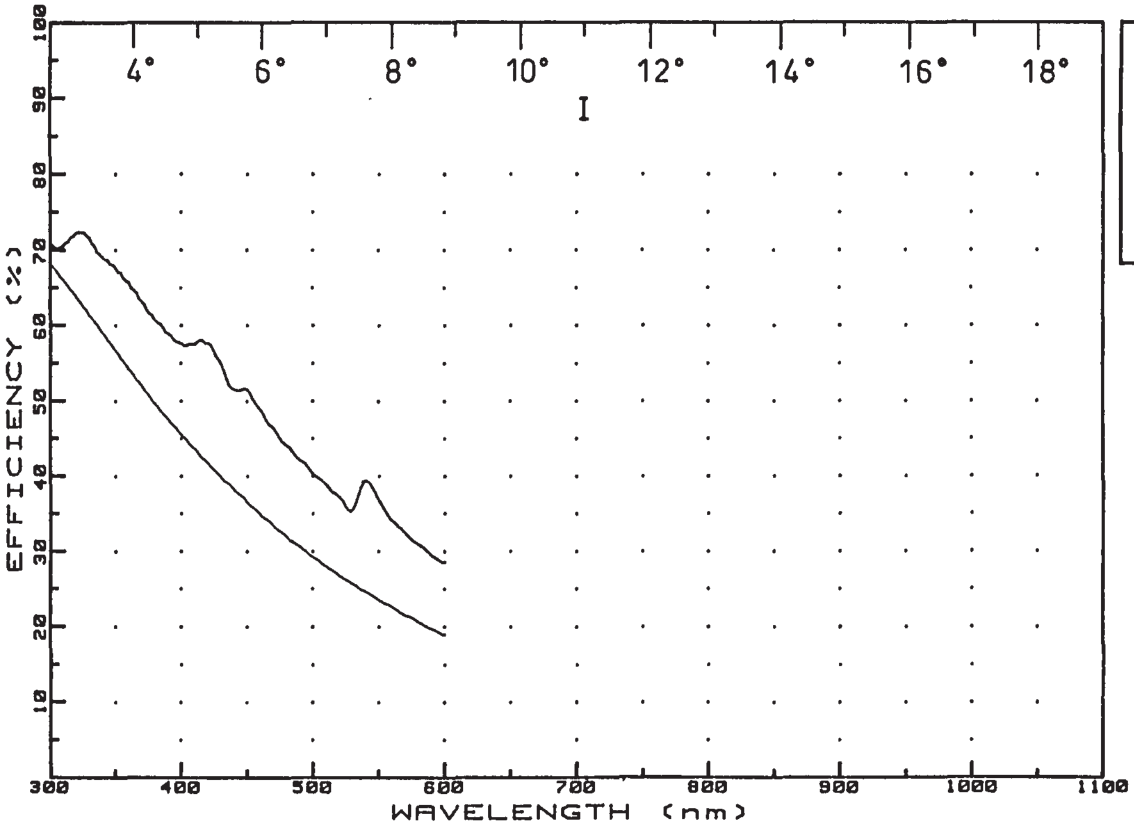
Grating 27
600 gr mm^{-1}
114 Å mm^{-1}
θ=11^{0}21$'$



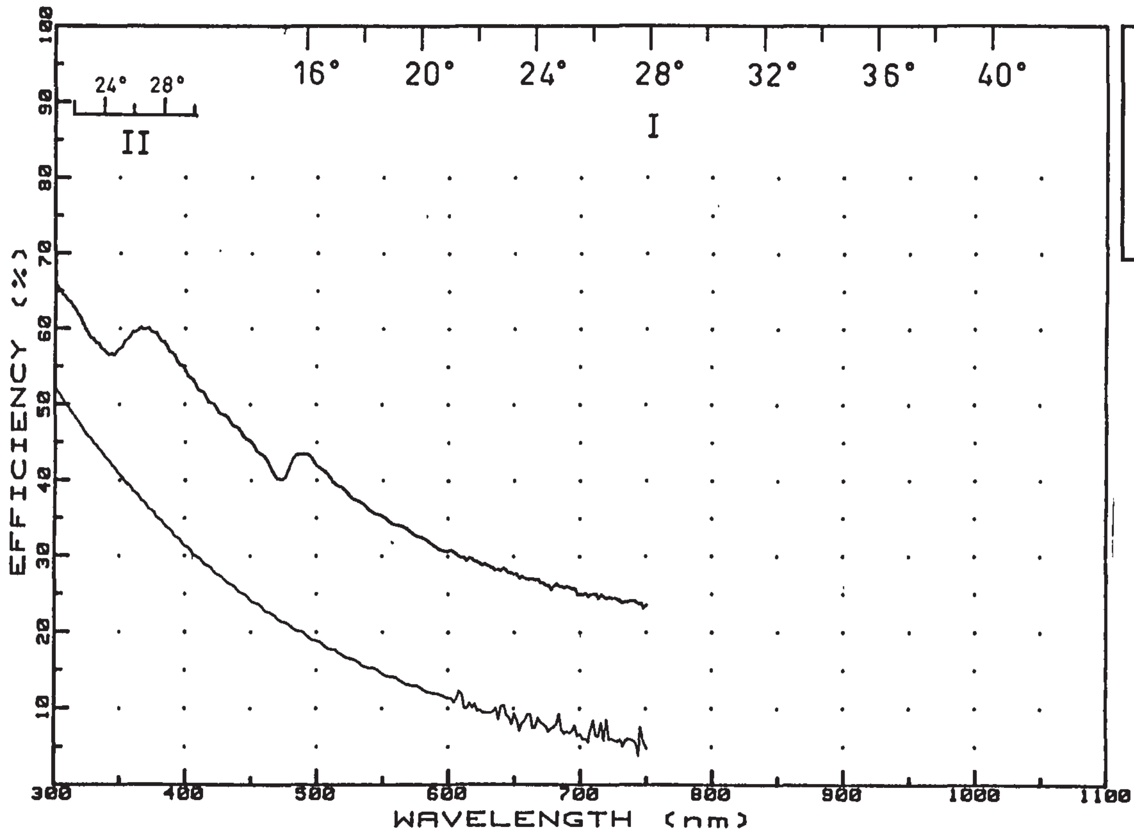
Grating 28
600 gr mm^{-1}
118 Å mm^{-1}
θ=17^{0}27$'$



Grating 29
600 gr mm^{-1}
112 Å mm^{-1}
θ=5^{0}10$'$



Grating 30
600 gr mm^{-1}
112 Å mm^{-1}
θ=5^{0}10$'$



Grating 31
1200 gr mm^{-1}
56 Å mm^{-1}
θ=10^{0}22$'$

Appendix D

Focusing the Spectrograph

- Obtain two well exposed He-Ar spectra, one with the upper Hartmann shutter in and one with the lower Hartmann shutter in.
- Enter IHAP mode and type: `BSET,888,0`.
- Then type: `BATCH,BCCFF,,#arc1,#arc2` (the last two arguments can be omitted if the arcs are the last two files on the disk).
- You will then see an arc spectrum plotted on a screen before you. You must now select the "high-cut" with the cursor. Press return and the spectrum will be replotted with the new cut value.
- You should now choose a number of lines. The lines should be not blended, chosen too close to each other, or asymmetric. About 10 lines are normally enough. Type the space bar to finish.
- The program will then plot for each selected line the dispersion offset between the two Hartmann exposures. Bad points can be edited out by using the `TEDIT` command. After typing this a cursor will appear on the plot. Use the cursor keys to edit out the bad points by placing the cursor over the point to be deleted and then press RETURN. After the last point has been deleted, press the space bar to exit from `TEDIT`.
- The program terminates by printing how many pixels shift there is between the two He-Ar spectra. *The focus is considered good if this is 0.2 pixels or less.* If the shift is larger than this call the operations group (phone 93 then 54) for advice. **DO NOT ATTEMPT TO MAKE ANY ADJUSTMENTS YOURSELF.**

Appendix E

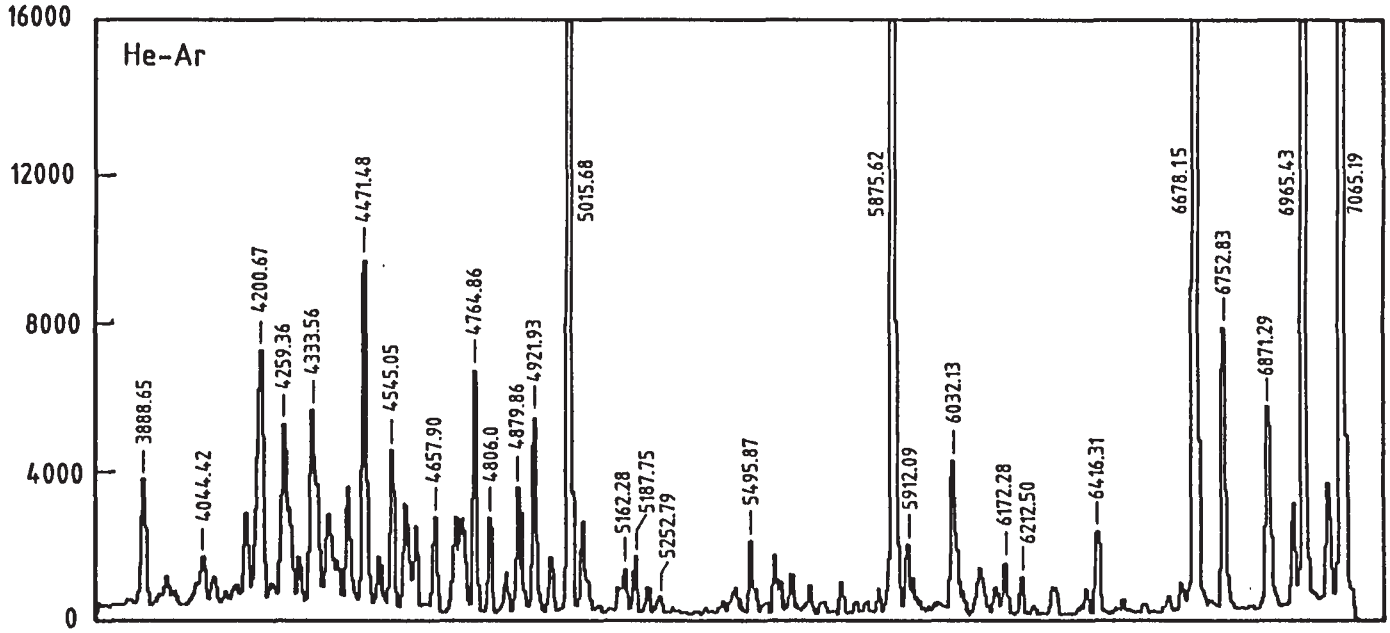
He-Ar Atlas

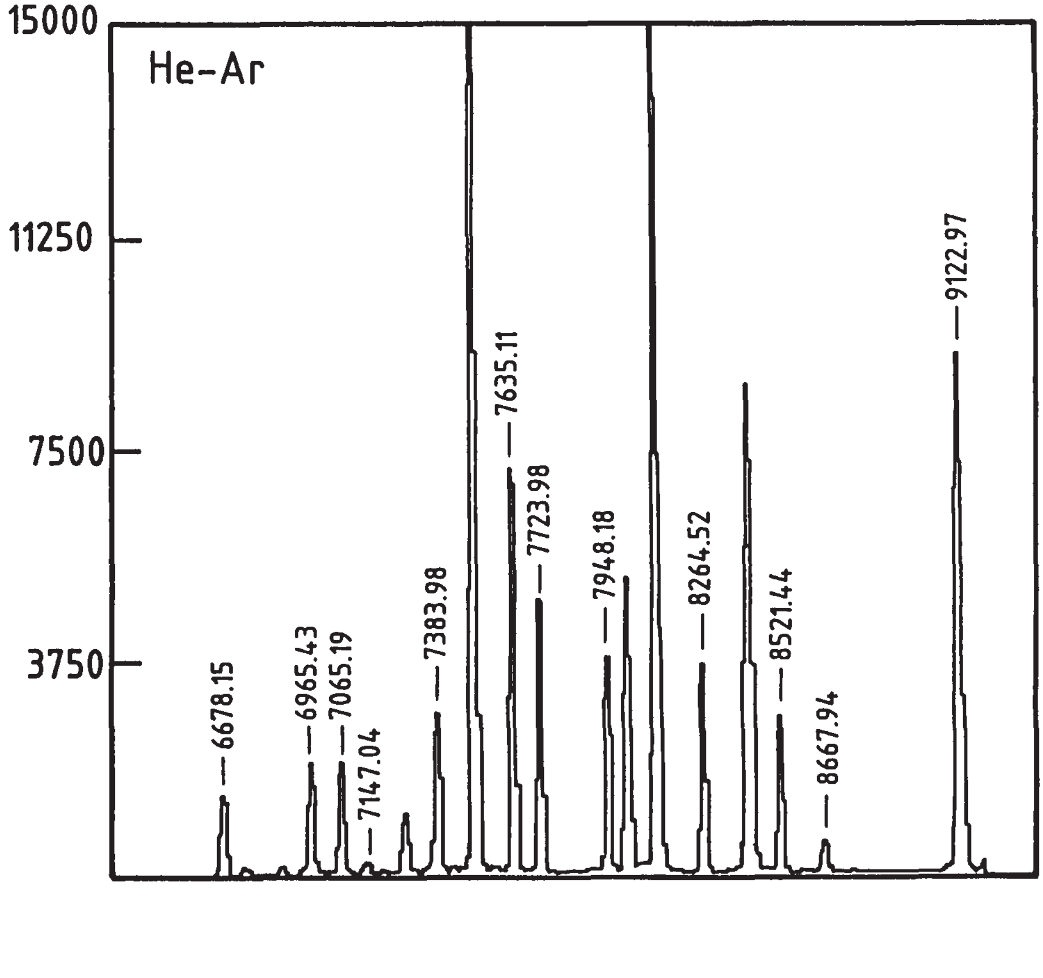
The main spectral lines in the He-Ar lamps used for wavelength calibration are listed in the table below.

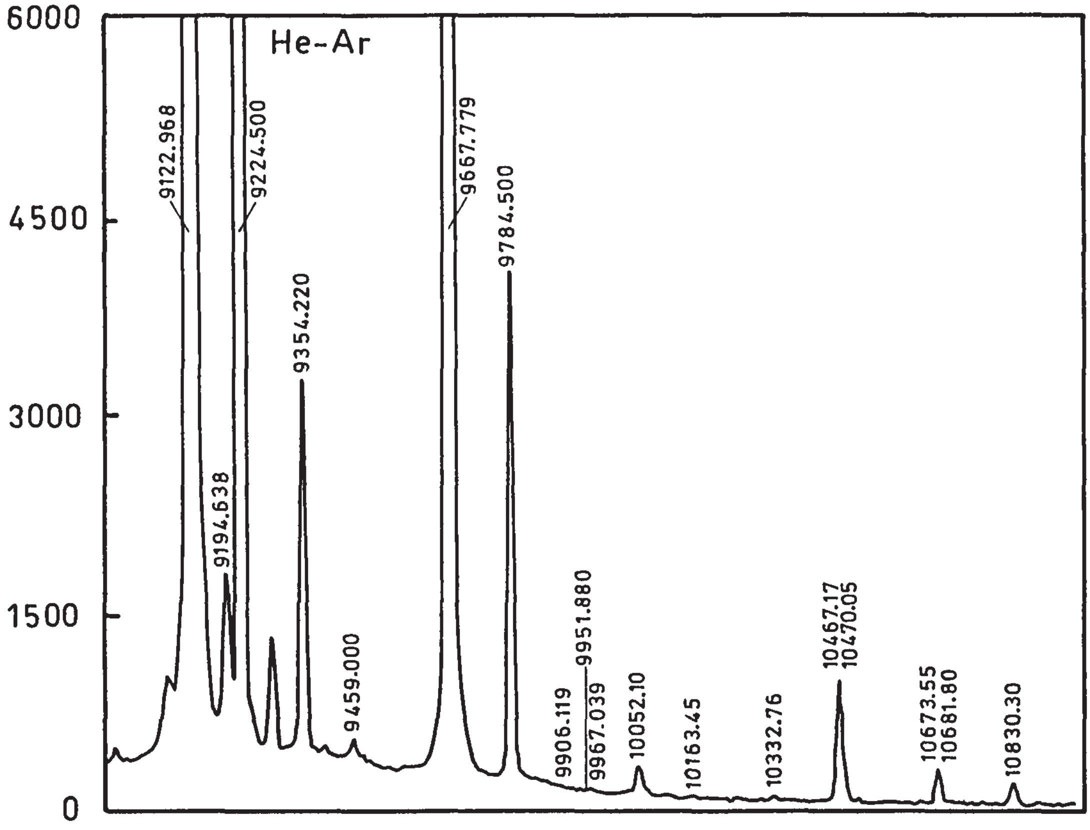
Main He-Ar Lines

λ	iden.	λ	iden.	λ	iden.
3639.83	Ar II	4713.15	He I	6871.29	Ar I
3718.21	Ar II	4764.86	Ar II	6937.66	Ar I
3729.31	Ar II	4806.02	Ar II	6965.43	Ar I
3737.89	Ar II	4879.86	Ar II	7030.25	Ar I
3765.51	Ar II	4921.93	He I	7065.19	He I
3780.84	Ar II	5015.68	He I	7147.04	Ar I
3803.17	Ar II	5047.74	He I	7272.94	Ar I
3809.46	Ar II	5162.28	Ar I	7383.98	Ar I
3819.60	He I	5187.75	Ar I	7635.11	Ar I
3850.58	Ar II	5221.27	Ar I	7723.98	Ar I
3868.52	Ar II	5252.79	Ar I	7948.18	Ar I
3888.65	He I	5421.35	Ar I	8115.31	Ar I
3928.62	Ar II	5495.87	Ar I	8264.52	Ar I
3948.98	Ar II	5558.70	Ar I	8521.44	Ar I
3964.72	He I	5606.73	Ar I	8667.94	Ar I
4026.19	He I	5650.70	Ar I	9122.97	Ar I
4044.42	Ar I	5739.52	Ar I	9224.50	Ar I
4072.00	Ar II	5772.11	Ar I	9291.58	Ar I
4148.88	Ar I	5802.08	Ar I	9354.22	Ar I
4158.59	Ar I	5834.26	Ar I	9657.78	Ar I
4191.03	Ar I	5875.62	He I	9784.50	Ar I
4200.67	Ar I	5912.09	Ar I	10673.55	Ar I
4228.16	Ar II	6032.13	Ar I	10829.09	He I
4259.36	Ar I	6105.64	Ar I	10830.25	He I
4300.10	Ar I	6172.28	Ar II	10830.34	He I
4333.56	Ar I	6212.50	Ar I	11078.87	Ar I
4348.06	Ar II	6296.87	Ar I	12112.20	Ar I
4387.93	He I	6369.57	Ar I	12402.88	Ar I
4400.99	Ar II	6384.72	Ar I	12439.19	Ar I
4471.48	He I	6416.31	Ar I	12456.05	Ar I
4545.05	Ar II	6604.85	Ar I	12487.63	Ar I
4579.35	Ar II	6643.70	Ar II	12784.79	He I
4589.90	Ar II	6678.15	He I	12802.74	Ar I
4609.57	Ar II	6752.83	Ar I	12956.59	Ar I
4657.90	Ar II				

The spectral lines are shown in the following figures.






6000
4500
3000
1500
0
He-Ar
9122.968
9224.500
9194.638
9354.220
9459.000
9667.779
9784.500
9906.119
9951.880
9967.039
10052.10
10163.45
10332.76
10467.17
10470.05
10673.55
10681.80
10830.30

Appendix F

Atmospheric Differential Refraction

The table gives atmospheric differential refraction in arcseconds as a function of airmass (sec z) for wavelengths between 3000 Å and 10000 Å, referenced to a wavelength of 5000 Å. For example, at an airmass of 1.5 the differential refraction between 4000 Å and 6000 Å is 1.08 arcseconds. At an airmass of 3.0, it is 2.75 arcseconds!

Since differential refraction occurs in a direction perpendicular to the horizon, the ideal slit position angle is also perpendicular to the horizon. In other words when the object is on the meridian, the position angle of the slit should be 0° or 180°. This angle (called the parallactic angle) will change as the object's distance from the meridian changes. If observers want to find the correct slit position angle as a function of hour angle and declination to minimise light losses due to differential refraction, they can use the curves presented in Figure F.1.

The parallactic angle is displayed on the TCS monitor at the 3.6 m telescope.

Table F.1: Atmospheric differential refraction at an altitude of 2 km in arcseconds with respect to a wavelength of 5000 Å.

sec z	3000	3500	4000	4500	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000
1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.05	0.68	0.38	0.20	0.08	0.00	-0.06	-0.11	-0.14	-0.17	-0.19	-0.21	-0.23	-0.24	-0.25	-0.26
1.10	0.97	0.55	0.29	0.12	0.00	-0.09	-0.15	-0.20	-0.24	-0.28	-0.30	-0.32	-0.34	-0.36	-0.37
1.15	1.20	0.68	0.36	0.15	0.00	-0.11	-0.19	-0.25	-0.30	-0.34	-0.38	-0.40	-0.42	-0.44	-0.46
1.20	1.40	0.80	0.42	0.17	0.00	-0.13	-0.22	-0.30	-0.35	-0.40	-0.44	-0.47	-0.50	-0.52	-0.54
1.25	1.59	0.90	0.48	0.20	0.00	-0.14	-0.25	-0.33	-0.40	-0.45	-0.50	-0.53	-0.56	-0.59	-0.61
1.30	1.76	1.00	0.53	0.22	0.00	-0.16	-0.28	-0.37	-0.44	-0.50	-0.55	-0.59	-0.62	-0.65	-0.67
1.35	1.92	1.09	0.58	0.24	0.00	-0.17	-0.30	-0.40	-0.48	-0.55	-0.60	-0.64	-0.68	-0.71	-0.73
1.40	2.07	1.18	0.62	0.26	0.00	-0.19	-0.33	-0.44	-0.52	-0.59	-0.65	-0.69	-0.73	-0.77	-0.79
1.45	0.22	1.26	0.67	0.28	0.00	-0.20	-0.35	-0.47	-0.56	-0.63	-0.69	-0.74	-0.79	-0.82	-0.85
1.50	2.37	1.34	0.71	0.29	0.00	-0.21	-0.37	-0.50	-0.60	-0.68	-0.74	-0.79	-0.84	-0.87	-0.91
1.55	2.51	1.42	0.75	0.31	0.00	-0.23	-0.40	-0.53	-0.63	-0.72	-0.78	-0.84	-0.89	-0.93	-0.96
1.60	2.64	1.50	0.80	0.33	0.00	-0.24	-0.42	-0.56	-0.67	-0.75	-0.83	-0.88	-0.93	-0.98	-1.01
1.65	2.78	1.58	0.84	0.34	0.00	-0.25	-0.44	-0.59	-0.70	-0.79	-0.87	-0.93	-0.98	-1.03	-1.06
1.70	2.91	1.65	0.88	0.36	0.00	-0.26	-0.46	-0.61	-0.73	-0.83	-0.91	-0.97	-1.03	-1.07	-1.11
1.75	3.04	1.73	0.92	0.38	0.00	-0.27	-0.48	-0.64	-0.77	-0.87	-0.95	-1.02	-1.07	-1.12	-1.16
1.80	3.17	1.80	0.95	0.39	0.00	-0.29	-0.50	-0.67	-0.80	-0.90	-0.99	-1.06	-1.12	-1.17	-1.21
1.85	3.29	1.87	0.99	0.41	0.00	-0.30	-0.52	-0.69	-0.83	-0.94	-1.03	-1.10	-1.16	-1.22	-1.26
1.90	3.42	1.94	1.03	0.42	0.00	-0.31	-0.54	-0.72	-0.86	-0.98	-1.07	-1.14	-1.21	-1.26	-1.31
1.95	3.54	2.01	1.07	0.44	0.00	-0.32	-0.56	-0.75	-0.89	-1.01	-1.11	-1.19	-1.25	-1.31	-1.36
2.00	3.67	2.08	1.10	0.45	0.00	-0.33	-0.58	-0.77	-0.92	-1.05	-1.15	-1.23	-1.30	-1.35	-1.40
2.10	3.91	2.22	1.18	0.48	0.00	-0.35	-0.62	-0.82	-0.99	-1.12	-1.22	-1.31	-1.38	-1.44	-1.50
2.20	4.15	2.36	1.25	0.51	0.00	-0.37	-0.66	-0.87	-1.05	-1.18	-1.30	-1.39	-1.47	-1.53	-1.59
2.30	4.38	2.49	1.32	0.54	0.00	-0.40	-0.69	-0.92	-1.11	-1.25	-1.37	-1.47	-1.55	-.162	-1.68
2.40	4.62	2.62	1.39	0.57	0.00	-0.42	-0.73	-0.97	-1.16	-1.32	-1.44	-1.55	-1.63	-1.70	-1.77
2.50	4.85	2.75	1.46	0.60	0.00	-0.44	-0.77	-1.02	-1.22	-1.38	-1.52	-1.62	-1.71	-1.79	-1.86
2.60	5.08	2.88	1.53	0.63	0.00	-0.46	-0.80	-1.07	-1.28	-1.45	-1.59	-1.70	-1.80	-1.88	-1.94
2.70	5.31	3.01	1.60	0.66	0.00	-0.48	-0.84	-1.12	-1.34	-1.51	-1.66	-1.78	-1.88	-1.96	-2.03
2.80	5.54	3.14	1.67	0.69	0.00	-0.50	-0.88	-1.17	-1.40	-1.58	-1.73	-1.85	-1.96	-2.04	-2.12
2.90	5.76	3.27	1.74	0.71	0.00	-0.52	-0.91	-1.21	-1.45	-1.64	-1.80	-1.93	-2.04	-2.13	-2.20
3.00	5.99	3.40	1.80	0.74	0.00	-0.54	-0.95	-1.26	-1.51	-1.71	-1.87	-2.00	-2.12	-2.21	-2.29
3.10	6.21	3.53	1.87	0.77	0.00	-0.56	-0.98	-1.31	-.1.57	-1.77	-1.94	-2.08	-2.19	-2.29	-2.38
3.20	6.44	3.65	1.94	0.80	0.00	-0.58	-1.02	-1.36	-1.62	-1.84	-2.01	-2.15	-2.27	-2.38	-2.46
3.30	6.66	3.78	2.00	0.83	0.00	-0.60	-1.05	-1.40	-1.68	-1.90	-2.08	-2.23	-2.35	-2.46	-2.55
3.40	6.88	3.91	2.07	0.85	0.00	-0.62	-1.09	-1.45	-1.73	-1.96	-2.15	-2.30	-2.43	-2.54	-2.63
3.50	7.10	4.03	2.14	0.88	0.00	-0.64	-1.12	-1.50	-1.79	-2.03	-2.22	-2.38	-2.51	-2.62	-2.72
3.60	7.32	4.16	2.20	0.91	0.00	-0.66	-1.16	-1.54	-1.85	-2.09	-2.29	-2.45	-2.59	-2.70	-2.80
3.70	7.54	4.28	2.27	0.94	0.00	-0.68	-1.19	-1.59	-1.90	-2.15	-2.36	-2.52	-2.66	-2.78	-2.88
3.80	7.76	4.41	2.34	0.96	0.00	-0.70	-1.23	-1.64	-1.96	-2.21	-2.42	-2.60	-2.74	-2.86	-2.97
3.90	7.98	4.53	2.40	0.99	0.00	-0.72	-1.26	-1.68	-2.01	-2.28	-2.49	-2.67	-2.82	-2.95	-3.05
4.00	8.20	4.66	2.47	1.02	0.00	-0.74	-1.30	-1.73	-2.07	-2.34	-2.56	-2.74	-2.90	-3.03	-3.14
4.10	8.42	4.78	2.53	1.04	0.00	-0.76	-1.33	-1.77	-2.12	-2.40	-2.63	-2.82	-2.97	-3.11	-3.22
4.20	8.64	4.90	2.60	1.07	0.00	-0.78	-1.37	-1.82	-2.18	-2.46	-2.70	-2.89	-3.05	-3.19	-3.30
4.30	8.85	5.03	2.67	1.10	0.00	-0.80	-1.40	-1.87	-2.23	-2.53	-2.77	-2.96	-3.13	-3.27	-3.39
4.40	9.07	5.15	2.73	1.12	0.00	-0.82	-1.44	-1.91	-2.29	-2.59	-2.83	-3.04	-3.21	-3.35	-3.47
4.50	9.29	5.27	2.80	1.15	0.00	-0.84	-1.47	-1.96	-2.34	-2.65	-2.90	-3.11	-3.28	-3.43	-3.55
4.60	9.51	5.40	2.86	1.18	0.00	-0.86	-1.51	-2.00	-2.40	-2.71	-2.97	-3.18	-3.36	-3.51	-3.64
4.70	9.72	5.52	2.93	1.21	0.00	-0.88	-1.54	-2.05	-2.45	-2.77	-3.04	-3.25	-3.44	-3.59	-3.72
4.80	9.94	5.64	2.99	1.23	0.00	-0.90	-1.57	-2.09	-2.51	-2.84	-3.10	-3.33	-3.51	-3.67	-3.80
4.90	10.15	5.77	3.06	1.26	0.00	-0.92	-1.61	-2.14	-2.56	-2.90	-3.17	-3.40	-3.59	-3.75	-3.88

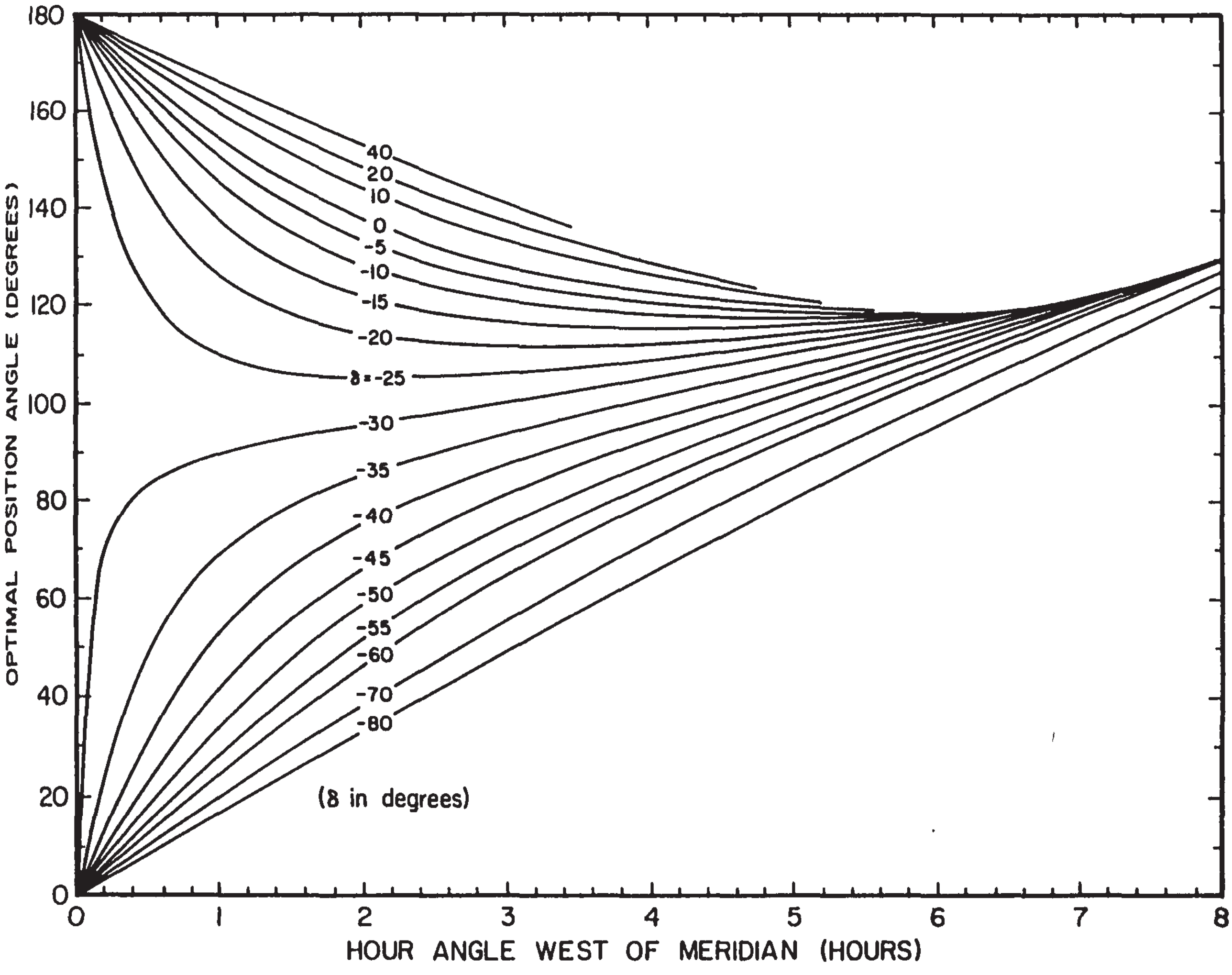


Figure F.1: Optimal slit position angle vs hour angle (for La Silla)

Appendix G

List of Standard Stars

G.1 Spectrophotometry

Here we present a list of 55 spectrophotometric standard stars with declinations below +30°. The columns are self-explanatory. The number of points available for each star and the wavelength range are shown in columns 6 and 7.

The finding charts are to be found in the binder *Spectrophotometric Standard Stars* at each telescope.

References

1) J. B. Oke: 1974, *Astrophys. J. Suppl. Ser.* **27**, 21

2) R. P. S. Stone: 1977, *Astrophys. J.* **218**, 767

3) R. P. S. Stone, J. A. Baldwin: 1983, *Monthly Notices Roy. Astron. Soc.* **204**, 347

4) P. Massey, K. Strobel: 1988, *Astrophys. J.* **328**, 315

Star	α (1950)	δ (1950)	m_{5556}	*Sp.*	*Points*	λ *Range*	*Ref.*
VMa2	00:46:31.0	+05:09:00	12.36	DG	409	3260–10640	1
L 870-2	01 35 26.3	-05 14 43	12.82	DA	156	3210–7220	1
Feige 15	01 46 28.5	+13 18 17	10.41	A1 V	29	3200–8370	2
LTT 1020	01 52 30.0	-27 42 00	11.5	g	41	3200–8280	3
PG 0250+134	02 05 21.3	+13 22 18	14.87	sdOB	99	3200–8100	4
PG 0216+032	02 16 43.0	+03 13 08	14.79	sdOC	99	3200–8100	4
Feige 24	02 32 30.9	+03 30 51	12.42	DAwke	109	3340–9440	1
Feige 25	02 36 00.0	+05 15 16	12.01	B6 V	29	3200–8370	2
PG 0310+149	03 10 49.9	+14 55 14	15.63	sdO	99	3200–8100	4
HZ 4	03 52 38.0	+09 38 35	14.57	DA	156	3210–7220	1
LB 1240	04 01 32.6	+25 00 54	13.94	DA	156	3210–7220	1
LB 227	04 06 36.7	+17 00 05	15.32	DA	156	3210–7220	1
HZ 2	04 09 57.2	+11 44 15	14.07	DA	156	3210–7220	1
40 Eri B	04 13 03.7	-07 44 09	9.55	DA	58	3320–9880	1
HZ 7	04 30 53.1	+12 37 12	14.30	DA	156	3210–7220	1
HZ 15	04 37 56.0	+08 35 00	12.59	B5	29	3200–8370	2
HZ 14	04 38 15.6	+10 53 57	13.94	DA	145, 99	3230–8100	1, 4
G 99-37	05 48 45.6	-00 11 16	14.51	DGp (CH)	59	3320–10040	1
Hiltner 600	06 42 37.2	+02 11 25	10.42	B1 V	29, 99	3200–8370	2, 4
L 745-46A	07 38 02.2	-17 17 24	12.91	DF	62	3320–10520	1
BD +8°2015	08 13 01.2	+07 46 28	10.39	G2: V	29	3200–8370	2
LTT 3218	08 39 36.0	-32 48 00	11.80	DA	10	3200–8090	3
LDS 235B	08 45 15.2	-18 48 31	15.66	DB	52	3320–8920	1
PG 0846+249	08 46 07.9	+24 56 25	16.94	DA1	90	3200–7650	4
PG 0939+262	09 39 58.8	+26 14 42	14.89	DA1	99	3200–8100	4
LTT 3864	10 30 00.0	-35 22 00	12.10	f	40	3200–8180	3
L 970-30	11 05 27.8	-04 52 51	12.97	DA	96	3180–9889	1
Ton 573	11 07 18.4	+26 35 12	15.87	DB	89	3340–8160	1
Ross 627	11 21 38.4	+21 38 05	14.12	DA, F	128	3160–10840	1
PG 1121+145	11 21 39.4	+14 30 18	16.97	DA1	99	3200–8100	4
GD 140	11 34 27.8	+30 04 35	12.41	DAn	110, 99	3160–10560	1, 4
EG 81	11 34 51.3	+14 26 58	13.30	sdO	99	3200–8100	4
LTT 4364	11 42 54.0	-64 34 00	11.50	C_2	41	3200–8280	3
Feige 56	12 04 13.8	+11 56 55	11.11	B5p	29	3200–8370	2
Feige 66	12 34 54.7	+25 20 31	10.54	sdO	99	3200–8100	4
LTT 4816	12 36 06.6	-49 33 00	13.80	DA	38	3200–7990	3
Feige 67	12 39 18.9	+17 47 24	11.89	sdO	99	3200–8100	4
HZ 43	13 14 00.7	+29 21 49	13.02	DAwk	61	3320–10520	1
Wolf 485A	13 27 39.6	-08 18 40	12.22	DA	57	3320–9889	1
CD-32°9927	14 08 49.3	-32 49 10	10.4	A0	40	3200–8180	3
Feige 98	14 36 04.1	+27 42 28	11.84	B7	29	3200–8370	2
GD 190	15 42 03.8	+18 16 12	14.66	DB	113	3210–10460	1
PG 1545+035	15 45 53.9	+03 32 03	14.34	sdOB	99	3200–8100	4
EG 274	16 20 12.0	-39 07 00	11.0	DA	39	3200–8090	3
Kopff 27	17 41 28.4	+05 26 04	10.31	A3 V	29	3200–8370	2
LTT 7379	18 32 54.0	-44 21 00	10.2	G0	40	3200–8180	3
BD +25°3941	19 42 21.9	+26 06 00	10.36	B1.5 V	29	3200–8370	2
LTT 7987	20 07 54.0	-30 22 00	12.2	DA	40	3200–8180	3
Wolf 1346	20 32 13.8	+24 53 52	11.54	DA	218, 99	3210–10640	1, 4
LDS 749B	21 29 41.3	+00 01 55	14.70	DB	179	3210–10200	1
L 1363-3	21 40 22.5	+20 46 45	13.28	DC	62	3320–10520	1
L 930-80	21 44 57.6	-07 58 03	14.97	DB	53	3320–9240	1
BD +28°4211	21 48 57.1	+28 37 48	10.56	sdOp	29, 99	3200–8370	2, 4
LTT 9239	22 50 00.0	-20 50 00	12.00	f	35	3200–7550	3
Feige 110	23 17 23.5	-05 26 22	11.88	sdO	29, 99	3200–8370	2, 4

G.2 Radial Velocity Standards

The observation of standard radial velocity stars is necessary to determine the zero point of velocity in programs studying accurate radial velocities. In the table presented here you will find a list of radial velocity standards covering a range of magnitudes and spectral types throughout the sky visible from La Silla. These have been taken from *Trans. IAU* (1955), **9**, 442 and *Trans. IAU* (1967), **13B**, 170. Note that it has been reported by Maurice (*Trans, IAU*, (1976), **16A**, 157 and Ardeberg and Maurice (*Astron. Astrophys.* 54, 233) that the stars from the latter reference may have a 6 km s^{-1} difference with respect to bright IAU standards. However, even at the highest dispersions and most careful reduction this is generally better than the accuracy that can be achieved with the B & C. If finding charts are required for these stars the reader is referred to the La Silla library.

Radial Velocity Reference Stars

HD/ CPD No.	SAO No.	SAO Coordinates 1950.0 α	δ	V	B-V	Spectral type	RV ± PE km s^{-1}
Southern stars fainter than eight magnitude (*)							
6655	255736	$01^h03^m43^s.5$	−72°49′12″	8.04	0.55	G3 IV-V	+15.5±0.5
24331	216515	03 48 52.9	−42 43 26	8.59	0.91	K2 V	+22.4±0.5
39194	256232	05 45 05.8	−70 10 46	8.09	0.46	K0 V	+14.2±0.4
−43°2527	217998	06 30 44.4	−43 28 57	8.61	1.15	K1 III	+13.1±0.5
48381	197096	06 39 52.6	−33 25 13	8.48	1.05	K0 IV	+39.5±0.5
83443	221348	09 35 14.8	−43 02 43	8.21	0.81	K0 V	+27.6±0.5
83516	200582	09 35 56.3	−34 50 59	8.63	0.97	G8 IV	+42.0±0.5
101266	222933	11 36 23.5	−45 05 04	9.29	0.65	G5 IV	+20.6±0.5
111417	223690	12 46 44.1	−45 33 11	8.33	1.41	K3 V	−16.0±0.5
120223	224454	13 46 03.7	−43 29 07	8.97	0.97	G8 IV	−24.1±0.6
176047	210794	18 56 26.2	−34 32 22	8.10	0.96	K1 III	−40.7±0.5
193231	246544	20 17 48.0	−54 58 12	8.39	0.73	G8 V	−29.1±0.6
196983	212352	20 38 42.3	−34 04 02	9.08	1.18	K2 III	− 8.0±0.6
219509	255448	23 14 13.6	−67 11 11	8.69	1.06	K5 V	+62.3±0.5
Stars with 4.3 < V < 8.0							
693	147133	00 08 43.2	−15 44 32	5.0	0.5	dF5	+14.7±0.2
8779	129300	01 23 53.6	−00 39 29	6.5	1.0	gK0	− 5.0±0.6
22484	111292	03 34 19.1	+00 14 40	4.4	0.6	dF9	+27.9±0.1
35410	132070	05 21 56.3	−00 56 16	5.2	1.0	gK0	+20.5±0.2
44131	133118	06 17 29.3	−02 55 18	5.2	1.5	gM1	+47.4±0.3
51250	152123	06 53 49.1	−13 58 39	5.2	1.5	M0	+19.6±0.5
66141	116260	07 59 39.9	+02 28 24	4.5	1.4	gK4	+70.9±0.3
80170	200185	09 14 59.4	−39 11 28	5.4	1.1	K5	00.0±0.2
89736	221970	10 18 14.1	−47 26 50	5.6	1.7	K0	+16
92588	137728	10 38 51.5	−01 28 42	6.4	1.0	sgK1	+42.8±0.1
107328	119341	12 17 48.5	+03 35 27	5.1	1.1	gK1	+35.7±0.3
126053	120424	14 20 41.7	+01 28 30	6.3	0.7	dG3	−18.5±0.4
136202	120946	15 16 45.4	+01 57 12	5.2	0.5	dF6	+53.3±0.2
154417	122056	17 02 44.0	+00 46 28	5.9	0.5	dF8	−17.4±0.3
157457	244734	17 22 05.8	−50 35 24	5.2	0.9	K1	+17.4±0.2
171391	161632	18 32 15.6	−11 01 04	5.2	1.0	gG7	+ 6.9±0.2
203638	190295	21 21 19.7	−21 03 56	5.5	1.2	gK2	+21.9±0.1
212943	127540	22 25 19.6	+04 26 39	4.9	0.9	sgK0	+54.3±0.3
223311	146919	23 45 58.3	−06 39 30	6.3	1.4	gK4	−20.4±0.1
223647	258989	23 49 14.4	−82 17 49	5.1	0.7	G7	+13.8±0.4

(*): According to Trans. IAU (1967; Prague, Commission 30) 13B 170.

Radial Velocity Reference Stars (Continued)

HD/ CPD No.	SAO No.	SAO Coordinates 1950.0 α	δ	V	B-V	Spectral type	RV ± PE km s^{-1}
Stars brighter than magnitude 4.3 (*)							
4128	147420	$00^h41^m04^s.8$	−18°15′39″	2.04	1.02	gG6	+13.1±0.1
18884	110920	02 59 39.7	+03 53 41	2.52	1.64	gM2	−25.8±0.1
36079	170457	05 26 06.1	−20 47 53	2.84	0.82	gG1	−13.5±0.1
36673	150547	05 30 31.4	−17 51 24	2.59	0.22	cF3	+24.7±0.2
45348	234480	06 22 50.5	−52 40 03	0.73	0.16	cF0	+20.5±0.1
81797	136871	09 25 07.8	−08 26 27	1.99	1.41	gK5	− 4.4±0.2
102870	119076	11 48 05.4	+02 02 48	3.61	0.55	dF8	+ 5.0±0.2
108903	240019	12 28 22.7	−56 50 00	1.62	1.60	M4	+21.3±0.1
109379	180915	12 31 45.3	−23 07 14	2.66	0.89	gG4	− 7.0±0.0
146051	141052	16 11 43.3	−03 34 01	2.72	1.58	gM0	−19.8±0.0
150798	153700	16 43 21.1	−68 56 20	1.91	1.44	K5	− 3.7±0.2
156014	102680	17 12 21.9	+14 26 45	3.1	.	gM5	−32.5±0.0
161096	122671	17 41 00.0	+04 35 12	2.77	1.16	gK1	−12.0±0.1
168454	186681	18 17 47.6	−29 51 05	2.70	1.38	gK2	−20.0±0.0
186791	105223	19 43 52.9	+10 29 24	2.62	.	gK4	− 2.1±0.2
204867	145457	21 28 55.7	−05 47 32	2.89	0.84	cG0	+ 6.7±0.1
206778	127029	21 41 43.8	+09 38 42	2.42	1.56	cK0	+ 5.2±0.2
222368	128310	23 37 22.6	+05 21 19	4.13	0.51	dF5	+ 5.3±0.2
O-type stars							
148937	226891	16 30 09.7	−48 00 24	6.89	0.20	B0	−43.5± <20
151804	227313	16 48 04.2	−41 08 48	5.22	0.08	O8f	−46.7± <20
152408	227425	16 51 28.8	−41 04 16	5.82	0.19	O8fp	−71.6± <20
B-type stars							
182422	087148	19 21 36.1	+20 09 58	6.47	.	B8 V	−25.7
183227	124661	19 25 50.1	+02 49 38	5.92	.	B9	−12.2
186122	105156	19 39 52.0	+12 04 29	6.24	.	B8 III	−22.3
189090	105471	19 55 29.1	+16 39 12	5.36	.	B9 IV	−26.7±2.6
196426	144632	20 34 44.6	−00 04 41	6.11	.	B8	−17.0±0.9
198667	144889	20 49 30.1	−05 41 45	5.43	.	B9 s	− 3.8±1.3
200340	145050	21 00 25.0	−01 07 23	6.26	.	B8	−12.9±4.5
213998	146181	22 32 47.2	−00 22 33	4.13	.	B8 V	−10.0±1.3

(*): According to Trans. IAU (1955) 9, 442.

Appendix H

Sample Grating Request Form

B & C set-up request

Name of observer :
Date of observation :

Telescope

3.6 m   **2.2 m**   **1.52 m**

Grating #:
Spectral range :

Give λ-min and λ-max or central λ

FILTERS:
(order separators)

SLIT WIDTH:
(in arc seconds)

1.52 m telescope

Telescope side :   EAST :   WEST :