Operation of the MMT Spectrograph

Version 4

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Multiple Mirror Telescope Observatory

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Preface

This manual supercedes all previous versions of the MMT Spectrograph Manual. We have attempted to streamline the manual by removing sections which were redundant in that their material is adequately covered in other documentation (e.g. the discussion of the Instrument Rotator, the Mount, etc.). In addition, we have included a description of the use of Red Channel.

Much of this manual is due to the contributions of Ray Weymann prior to his departure from Steward Observatory. We are indebted to Ray for his care and attention to detail in earlier versions of this manual.

We thank Cheryl Pagnotta for her renditions of the optical layout of the spectrograph on the cover and in Figures 2.3 and 2.4.

Please direct any questions, corrections or omissions to us.

Craig Foltz
Dave Ouellette

November 15, 1988

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Chapter 1

Introduction

1.1 The Spectrograph(s)

1.1.1 General Description

The MMT Spectrograph is really two spectrographs, The Blue Channel and the Red Channel, which share a common entrance aperture assembly and two filter wheels. Both can be run remotely from either the control room or the downtown remote observing room, though the two cannot be run simultaneously.

The Blue Channel is a photon-counting spectrometer with spectral resolution which runs from about 0.5 Å FWHM (with the echellette grating and the Image Stacker) to $\sim$ 10 Å. It is sensitive from 3200 Å to about 7000 Å with decreasing sensitivity further to the red. The Red Channel utilizes a TI 800 $\times$ 800 thinned CCD for spectroscopy in the range 3800 Å - 1.0 micron at somewhat lower resolution but with higher throughput than the Blue Channel. Mechanical control of both spectrographs is accomplished via user-friendly software systems (called BCCS and RCCS for the Blue and Red Channels, respectively) running on an IBM PC. Detector control is by two completely different user-hostile Forth systems which run on the Point 4 Instrument Computer.

The spectrograph is attached to the telescope via the general instrument interface called the Top Box. The Top Box contains the television acquisition and guider systems as well as the comparison source feeds for use with the spectrograph.

The telescope, data system and spectrograph form a complex system and first-time users are very strongly encouraged to spend at least the first half of a night with an experienced user rather than to rely on manuals.

The Blue Channel image tube chain (called Big Blue) is extremely vulnerable to damage and **USERS SHOULD READ SECTION 1.2, BELOW, BEFORE ATTEMPTING TO USE THE SPECTROGRAPH.** It is the responsibility of the user to be cognizant of the safety guidelines concerning the operation of Big Blue. Furthermore, the potential exists for damage to the Red Channel CCD. Therefore, before proceeding into the rest of the manual, please read the following section.

1.2 Observer's Responsibilities for the Protection of the Detectors

The blue image-tube chain driving the Reticon on the Blue Channel is a very valuable, very vulnerable, and virtually irreplaceable piece of equipment, as is the TI 800×800 CCD detector in the Red Channel. The loss or either would severely curtail the research of many astronomers. Therefore, all users of this instrument are requested to read the relevant section below with care: it spells out important safety procedures and precautions. It is the observer's responsibility to see that these are carried out.

1.2.1 Protection of the Big Blue Detector: Observer's Responsibilities

- **Whenever the high voltage is on and the camera shutter (not the dark position in the lower filter wheel; see spectrograph schematic) is open the flashing warning lights should be on, whether or not data are being taken. The switch for the warning light is located on the right side of the observer's workstation. Flashlights should be used in the telescope chamber when the warning lights are flashing unless the count rates are being monitored. Count rates above 2000 counts/side/s mean too much illumination – close the camera shutter.**

  The Top Box is equipped with a shutter which should be closed during afternoon setup. The shutter is closed by a rocker switch on the Top Box paddle which is located at the Telescope Operator's station. Ask for help from one of the day crew if you cannot find it. NOTE: When the comparison mirror is "out" and the camera shutter and Top Box shutter are open, high count rates may result even for very low levels of dome illumination, due to light reflected off the beam combiner.

- Always leave the spectrograph in a 'safe' configuration unless you need to have the camera shutter open and you have turned on the flashing warning lights. The safe configuration is obtained by (a) closing the camera shutter, and (b) setting the lower filter wheel to the Dark position. In this configuration the fluorescent and incandescent lights in the chamber may be used. The building shutters and mirror covers may be opened no earlier than one hour before sunset provided that the building is turned away from the sun. Monitor the counts carefully as the shutters are opening.

- Neither the solenoid power supply nor the solenoid cooling should be turned off during the run, except for a real emergency; in this case turn off the solenoid power before you turn off the solenoid cooling, but do so only after the image tubes are powered-down (see below).

- In the event that it was necessary to turn off the high voltage (Spellman) power supplies, or if a power failure has occurred, follow carefully the instructions contained in Appendix E. In particular, if there has been a power failure, or if the over-illumination sensor described below has turned off the power, do not turn the supplies back on until the voltage control knobs have been turned back to zero. Be careful not to exceed the posted voltages when turning up the supplies.

- Never illuminate the detector with a uniform continuum source yielding more than 3000 counts/side/s. Be especially careful of the illumination level with emission line lamps. Do not exceed 4 counts/pixel/s when sampling the spectrum into 2048 pixels or 2 counts/pixel/s when sampling into 4096 pixels for the strongest emission line.

- An over-illumination sensor has been installed as an extra measure of protection against damage by bright stars. Note that 'bright' for the 300 gpm grating is about $V = 15$. Whenever either of the two arrays senses a count rate of 6000 counts/side/s or greater a high-pitched alarm will sound. After 2 seconds the lower filter wheel will automatically be moved to the Dark position and the Top Box shutter will close. After 5 more seconds the high-voltage power supplies will be turned off if the counts are still high. Observers must not be lulled into a sense of security by this device.. Always exercise great caution and follow the procedures below. There are two reasons for this:

  1. Count rates very much higher than 6000 counts/side/s can result from, for example, SAO stars. This could destroy the image tube

in less than 2 seconds and may saturate the Reticon electronics so such count rates may not even be detected.

2. Turning off the high voltage power supply abruptly is in itself a risky operation and is to be avoided.

- When slewing to a new position or offsetting to an alignment star brighter than about V = 14, set the lower filter wheel to the Dark position by issuing the BCCS command `DARK`. When you have returned to your object and the TV has been turned up, confirm that there is no bright object in the aperture. The lower filter wheel may be set to the desired position with the `LFW` command.

- If a thunderstorm is nearby, the high voltage should be turned off as should the computers. If possible, the Telescope Operator should do this.

If you have any questions about the foregoing instructions you should contact Craig Foltz or Dave Ouellette before attempting to operate the spectrograph.

1.2.2 Protection of the TI CCD: Observer's Responsibilities

As most observers know, CCD detectors are very fragile and expensive items. Fortunately, once the CCD is installed in a cryogenic dewar it is relatively sturdy. The following precautions are to be observed by all observers:

- **Never** disassemble the dewar or the electronics box that is mounted on it (the camera head electronics). **Never** separate the camera head electronics box from the dewar.

- **Never** let air into the dewar. **Never** touch the valve at the rear of the dewar.

- **Never** disconnect or jiggle any cables.

- When thunderstorms are imminent and no MMTO personnel are available, turn off the CCD power supply, CCD controller, and Point 4 computer and peripherals. It is extremely rare that an observer is on the mountain alone. Please try to locate a staff member to do this.

1.3 In Case of Problems

The MMT Spectrograph is a complicated device. Its operation relies on the successful functioning of a wide range of systems including delicate detectors, a cryogenic dewar, an irreplaceable image tube, temperature controllers and three different software systems. Unfortunately, when describing the spectrograph, the adjective 'user-friendly' does not jump into mind. There are bound to be difficulties and problems the solution to which will not be found in this manual. If you have an instrumental problem which prevents you from collecting good data, call for help no matter what time it is. Do not attempt to fix hardware problems involving the spectrograph or detector systems without first obtaining explicit authorization from the Instrument Scientist or Instrument Specialist:

Instrument Scientist: Craig Foltz 621-1269 (O), 790-8640 (H)

Instrument Specialist: Dave Ouellette 621-7933 (O), 326-6129 (H)

If you are unable to contact either, call the MMTO on-call engineer. See the engineering calendar posted behind the operator's console or ask the Telescope Operator who is on call.

1.4 This Manual and Additional Documentation

This manual contains a reorganization of the material in the previous spectrograph manual and new sections describing the operation of the Red Channel. We have tried to make the manual more concise by stripping out information which can be found in other documents. Therefore, we have eliminated the sections dealing with control of the mount and instrument rotator, and the summary of the SAO Forth language. Details can be found in the manuals listed below. All of the documentation listed below as well as the most recent version of this manual are maintained in a documentation rack in the MMT Control Room.

- Control of the motor-driven spectrograph functions is covered in this manual at a level which should be adequate for the majority of observing programs. More detailed information about the BCCS and RCCS systems can be found in the *BCCS/RCCS/ECCS Manual.*

- First-time and infrequent users of Blue Channel with fairly straightforward observing programs should consult *MMT Technical Memorandum 84-10, "Abridged I-Ret Software Guide"* for a cookbook describing the data-taking software.

- A complete description of the Blue Channel detector control software can be found in the current version of the *I-RET Software Manual.* Questions about details of SAO Forth may be answered by consulting the *SAO Forth Manual.*

- Details of the Red Channel detector control not covered in this document can be found in the *Steward Observatory CCD Manual.*

- The *KPNO IIDS Standard Star Manual* contains finding charts and positions for bright standard stars. When using these stars with Blue Channel, keep in mind the illumination guidelines for the image tube. The lists of fainter standards by Fillippenko and by Massey *et al.* are also included.

- The current Reticon log sheets are contained in a blue binder labeled 'Current Reticon Log Sheets' (how original!). All logs from directory number 1 on are stored in a rack in the control room.

- Users not familiar with the MMT Mount commands may find it helpful to read the relevant sections of *MMT Technical Memorandum 84-23* which summarizes the basic concepts and commands of the Mount Control system and the Instrument Rotator operation and terminology.

1.5 A Few Words about the Computer Systems

As noted above, the spectrograph stepper motors are controlled by an IBM PC; the detectors by the Point 4 Instrument Computer. Keyboard input can be made from two separate keyboards or from the single IBM PC keyboard, with computer selection accomplished by toggling the F1 function key. Furthermore, the Point 4 can be accessed from either the keyboard in the Control Room or a terminal in the Computer Room. Control of these and other data entry options is accomplished by an array of switches at the

Observer's Console. Due to the staggering number of possible permutations of the switch settings, we recommend that users consult MMTO staff if they have any questions about the terminal configuration.

In what follows, we have discriminated between typed input to the computers and output appearing on the terminal by font. `This is the font used for commands, etc. typed by the user.` *This is the font used to represent output on the computer displays.*

Chapter 2

Optical Properties of the Spectrograph

2.1 MMT Top Box Optical Parameters

1. Distance from bottom of Top Box to MMT focal plane: 9.0 inches
2. Image scale at TV guider (assuming 15 mm detector format):
   (a) Canon 85 mm: 19.4 arcsec/mm; 5 arcmin field.
   (b) Canon 200 mm: 8.4 arcsec/mm; 2 arcmin field.
3. Comparison sources:
   (a) Fe-Ne (hollow cathode)
   (b) Th-Ar (hollow cathode - normally not available for spectrograph)
   (c) He-Ar (AC glow discharge)
   (d) Neon (low pressure discharge)
   (e) Hg-Cd - attenuated longward of 4000 Å with a U-330 filter.
   (f) Incandescent ('Bright' and 'Dim')
   (g) Etalon - several spacings are available.
4. Filter Wheels: Two filter wheels are mounted in front of the comparison lamp feed. One of them contains neutral density filters; the other, Hartmann masks. Note from Figure 2.2 that they do *not* occult the beam from celestial sources.

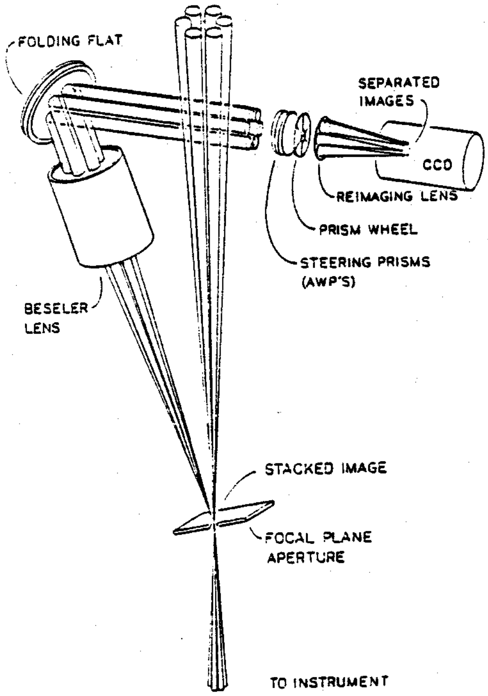


Figure 2.1: Acquisition and guiding television. Note that the prism wheels are not usually in the beam.

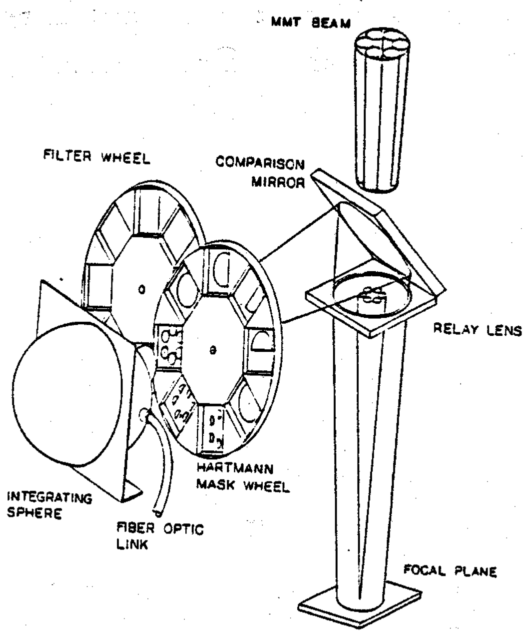


Figure 2.2: Comparison lamp feed layout.

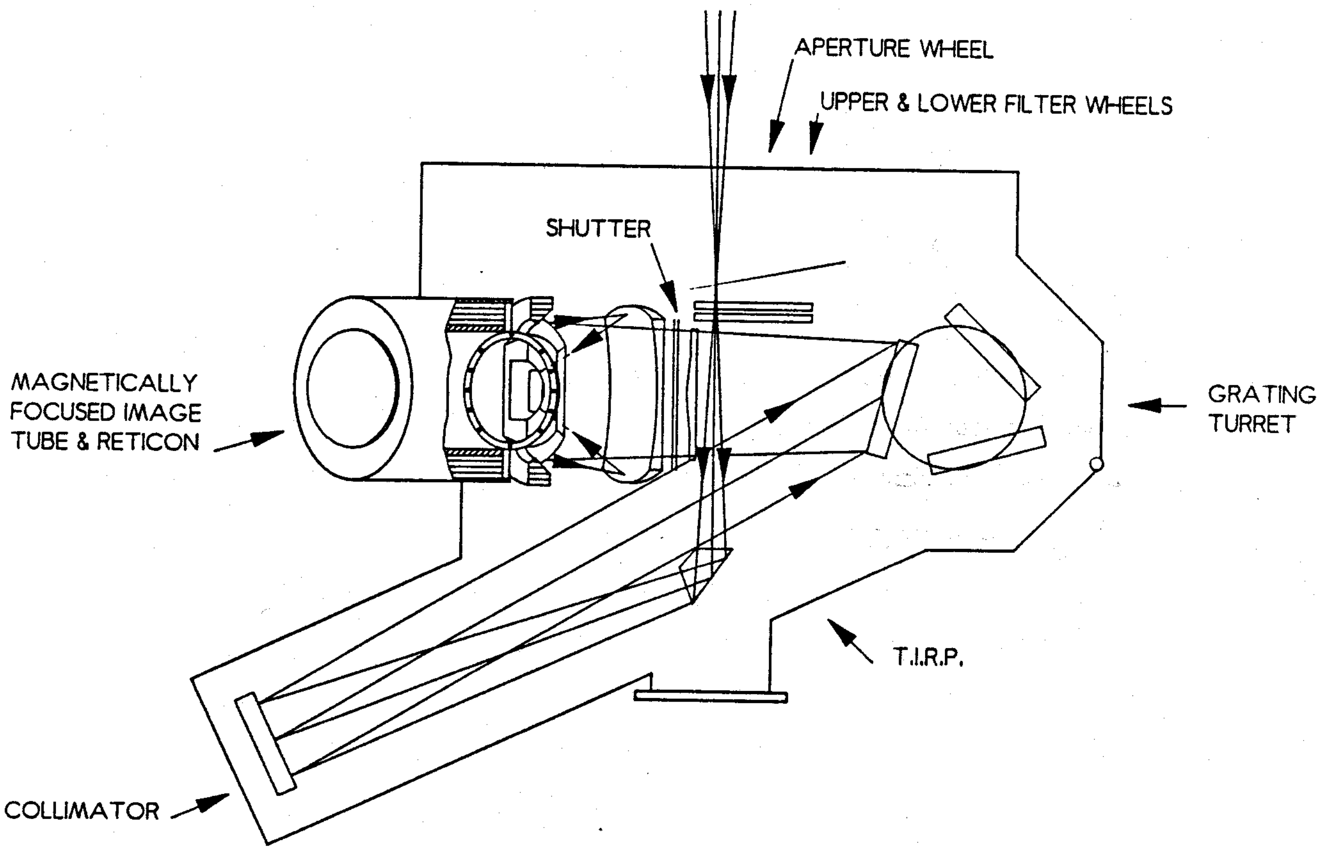


Figure 2.3: The Blue Channel optical layout.

2.2 MMT Spectrograph Blue Channel Optical Parameters

The Spectrograph layout is shown in Figure 2.3 The view shown is as seen with one's back to the observing chamber doors (i.e. facing north when the building is stowed normally).

1. Camera

   Type: folded Schmidt

   Focal length: 9.86 inches

   Monochromatic beam size: 6.0 inches

   Unvignetted field: 9.0 degrees

2. Collimator

   Type: off-axis paraboloid (10 degrees)

   Focal length: 54.25 inches

   Diameter: 8.0 inches

3. Folding Prism (TIRP)

   Type: Total Internal Reflection Prism (TIRP), 110 degree beam deviation

   Material: fused silica

   Beam steering range: ±7 arcmin (±0.5 mm at camera focus)

2.3 Shared Assemblies

1. Slit Assembly

   All sets of double circular holes or slits are + 0.128 inches on either side of optical axis. A vector normal to the slit assembly is tilted 12.5 degrees with respect to the optical axis. Available apertures:

   (a) 1.0 arcsec double circular holes *

   (b) 1.0 x 2.6 arcsec double slits

   (c) 1.4 arcsec double circular holes *

   (d) 2.0 x 3.0 arcsec double slits

(e) 5.0 arcsec double circular holes

(f) Image Stacker

(g) 3 arcsec single circular hole

(h) 1.25 x 180 arcsec slit *

(i) 2.0 x 180 arcsec slit *

(j) 5.0 x 180 arcsec slit *

(k) 1.25 x 20 arcsec slit *

(l) 2.0 x 20 arcsec slit *

(m) 5.0 x 20 arcsec slit *

(n) 1.25 x 90 arcsec slit for use with Red Channel prism*

(o) 90 arcsec circular hole for direct imaging with Red Channel *

Note that only seven aperture plates can be resident in the spectrograph at any one time. Aperture plates marked with *'s can be changed while the spectrograph is on the telescope; the rest cannot.

2. Upper and Lower Filter Wheels. Each wheel contains seven positions and a clear position. Each position can accommodate a 2×2 inch square filter with thickness up to about 6 mm. Filters cannot be changed without removing the spectrograph from the telescope. Contact the MMTO staff for special filtering requirements. Transmission curves for normally-available filters are presented in Appendix 4.

2.4 MMT Spectrograph Red Channel Optical Parameters

The spectrograph layout is shown below. Note that this view is from the same perspective as Figure 2.3, i.e. with the chamber doors at one's back.

1. Collimator. Two element lens of 6.0 inch clear aperture (3.75 inches used by axial beam).

   Focal Length: 33.75 in.

   Element 1: BaK5 meniscus. Outer surface is asphere.

   Element 2: Calcium Fluoride. Spherical both sides.

   Range of use: Achromatic from 3700 Å to 1 μ.

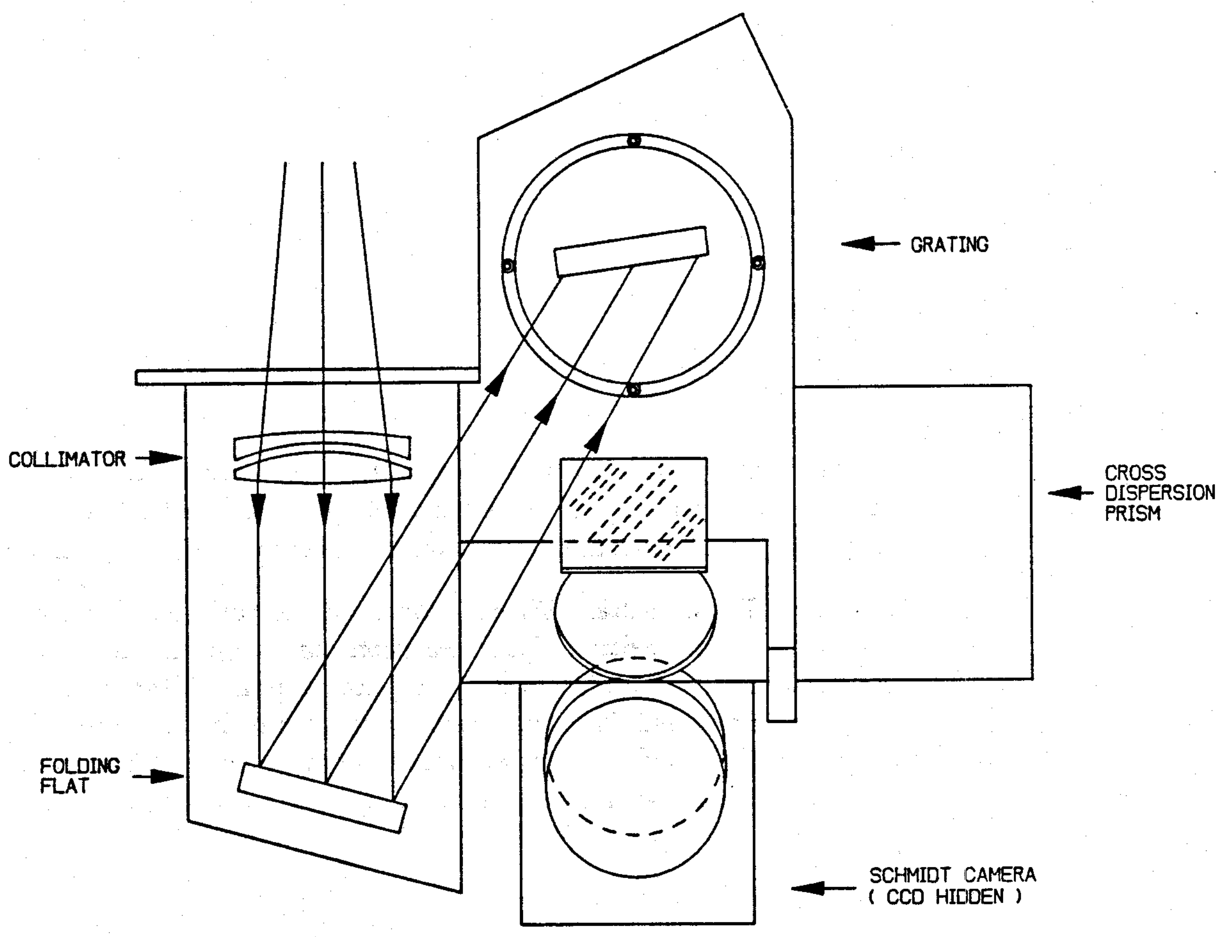


Figure 2.4: The Red Channel optical layout

2. Folding Flat. Approximately 6 inches in diameter. Fold angle = 32 degrees.

3. Gratings. Located at the pupil formed by the collimator.

   Beam diameter at pupil: 3.75 in.

   Ruled area: 102 mm × 128 mm.

   Camera/collimator angle: 32 degrees.

   Details of available gratings tabulated below.

4. Cross-dispersing Prism. 45 degree wedge of SF-6. Can be used as the primary disperser for low, nonlinear (3 Å/pixel at 5000 Å to 18 Å/pixel at 8700 Å) dispersion with high throughput.

5. Camera

   Folded Schmidt: focal length = 6.0 inches. f/1.6 monochromatic.

   Corrector element 1: LF5 meniscus. Both sides spherical.

   Corrector element 2: FK5 meniscus. Inner surface asphere.

   Corrector clear aperture: 5.75 in.

   Schmidt folding flat diameter: 6.75 in. Fold angle = 62 degrees.

   Sphere: Clear aperture = 6.90 inches, diameter = 7.00 inches. Radius of curvature = 12.46 in.

Thus the spectrograph demagnifies by 33.75/6.00 = 5.625. One second at the focal plane (0.270 mm) translates to 0.048 mm at the detector.

2.5 Gratings

There are currently five gratings available for use with the Blue Channel and five (plus a direct imaging flat) for use with Red Channel Any three of the former can be mounted in the Blue Channel grating turret and any one of these three can be quickly selected for use. Mounting and demounting of the gratings from the Blue Channel turret, however, is to be done only by the Instrument Specialist or Scientist and only during the day. The user *must specify in advance*, using the Observing Request Form, which three of the five gratings should be mounted. Three of the Red Channel gratings (or two gratings and the flat) can be mounted in the Red Channel grating slide. Grating interchange can be done by the Instrument Specialist or Scientist, or the Telescope Operator.

The turret and slide assignment for the gratings varies from run to run. The current values are posted on the white board in the Control Room.

2.5.1 Blue Channel Gratings

Grating	*Blaze Order/λ*	*Resolution* (Å)*	*Coverage (Å)*
Echellette**	12 / 4475	~ 0.5	filter-dependent
300	1 / 5000	6	4500
600	2 / 4800	1.3	1200
800	1 / 4000	2	1950
832	2 / 4300	1	900

* Resolution is FWHM of an unresolved emission line observed through a 1 arcsec slit.
** For a complete discussion of the echellette, see section 3.5.

2.5.2 Red Channel Gratings

Grating	*Blaze Order/λ*	*Resolution (Å)*	*Coverage (Å)*	*Blaze Angle (degrees)*	*Dispersion (Å/mm)*
Echellette	7 / 5134	5.6	1390	8.6	116
	6 / 5989	6.5	1630		136
	5 / 7187	7.8	1960		163
	4 / 8984	9.7	2440		203
150	1 / 4800	20.0	4800	2.15	425
270	1 / 7300	11.5	2870	5.9	239
600	1 / 6500	5.26	1300	11.4	107
1200	1 / 5767	2.1	650	21.1	54.6
1200	1 / 7700	1.9	640	28.7	53.3

Chapter 3

Operation of the Spectrograph — The Blue Channel

3.1 Detector System Components and Their Locations

3.1.1 Image Tube/Reticon/Solenoid Package

The image tube chains consists of a 3-stage image tube with fiber-optic coupling to a microchannel plate, which in turn is coupled to a V-shaped fiber bundle called a 'split boule' to which is attached the dual channel Reticon. This entire package is enclosed in a large cylinder which contains the solenoid cooling lines and windings. This solenoid-detector package is mounted at the focal plane of the camera on the spectrograph.

3.1.2 Cooling System

There are two separate cooling systems for Big Blue, one for the solenoid and the other for the image tube photocathode. The solenoid is cooled by a mixture of methanol and water which, in turn, is cooled by a Neslab refrigerator located in the level 2 instrument laboratory. The image tube cooling system is also a Neslab refrigerator in the level 3 instrument laboratory. The cooling lines from these refrigerators do not go through the instrument rotator and are too short to accommodate the full range of the rotator. Use great caution and watch these lines if you use the rotator.

3.1.3 Dry Air System

Dry nitrogen must always flow to the photocathode of the detector when the spectrograph is in use or frost will form, degrading the focus and ruining the spectra. Dry air is produced by an air-drying system in the Level 2 instrument laboratory which is backed-up by a dry nitrogen cylinder.

Flow of dry air is controlled by a valve on the front of the air drying system. A flowmeter above the valve measures the flow rates.

3.1.4 Reticon Head Power Supply and Electronics A/D Package

These are two small ($8 \times 6 \times 10$ inch) boxes mounted on the Southwest side of the spectrograph. The power supply has an on/off switch and red light.

3.1.5 Reticon Discriminator Electronics Box

There are actually two such boxes, one mounted above the other, in the second rack from the left in the floor directly above the control room where the computers are housed. One of the units is used for the Echelle Reticon and serves as a spare for the Big Blue discriminator box. There are two LED displays on this box which display the count rate from the detector whether or not the instrument computer is on. A third LED display indicates the photon event discriminator threshold voltage.

3.1.6 Solenoid Current Meter and Power Supply

These are located at the top of the right-most rack in the computer room as you stand with the instrument computer on your left. The meter unit also contains the solenoid overheating protect light and reset button.

3.1.7 Image Tube High Voltage Power Supplies

There are two separate supplies: the microchannel plate supply is the top most and is located beneath the solenoid power supply. Underneath the microchannel plate supply is the 3-stage tube supply. **Warning: do not make any adjustments to these supplies without the approval of the Instrument Specialist or Instrument Scientist.**

3.1.8 Temperature Readouts

The image tube temperature is displayed on an LED readout in the instrument support rack in the control room by the observer's console. This temperature should remain at $-25°$ C *at all times*. Depressing and holding the black button on the same chassis displays the temperature of the body of the spectrograph. Both displays are in degrees Centigrade.

3.2 Manually Operated Functions

3.2.1 Collimator Fine Focus

The fine focus is used to focus the spectrograph. To change the focus, turn the knob attached to the small aluminum box on the top of the collimator box (labeled). A small lever at the upper end of this box engages or disengages the focus gears. Leave them engaged; this is not a lock and the lever binds. The collimator focus is read out by the dial indicator labeled "fine focus". There are 2 small dials and one large dial all housed in a single dial indicator. One of the small dials will always read between 0.5 and 1.0. The second one will read between 0.25 and 0.40. The large dial reads between 0.000 and 0.050. The focus setting is the sum of the three: e.g. a focus of 0.828 is indicated by $(0.5 + 0.3 + 0.028 = 0.828)$. The limits are between about 0.75 and 0.90. Be careful not to drive the focus hard against these limits.

Increasing the numbers moves the collimator away from the slit; one unit on the dial is actually .006 inches of travel (i.e. going from 0.816 to 0.822 moves the collimator .036 inches away from the slit).

3.2.2 Coarse Collimator Motion

This motion is only used to switch the spectrograph back and forth between the slit (i.e. non-stacker) mode and the image-stacker mode. The position is read out with the dial indicator labeled "Coarse Focus" and should be 0.640 for the slit mode and 2.238 for the stacker mode. See Chapter 6 for details on switching modes.

3.2.3 Prism Height Adjustment

This motion adjusts the vertical height of the total internal reflection prism (TIRP) and is only used to switch the spectrograph back and forth between the slit and stacker mode. A dial indicator below the prism reads out the motion. It should read 0.465 for the slit mode and 0.760 for the stacker mode. See Chapter 6 instructions on switching modes.

3.3 BCCS Examples

The SCCS system is described in detail in the *BCCS/RCCS/ECCS Manual*. The following examples illustrate all of the commands needed to configure the spectrograph and should suffice for the novice user observing at the telescope (i.e. not remote). We assume that the Top Box is being run by the Observer's Paddle.

The functions which can be controlled and commands that control them are:

Function	*Command*
Aperture Wheel	`APERTURE`
Upper Filter Wheel	`UFW`
Lower Filter Wheel	`LFW`
TIRP Rotation	`TIRP`
Grating Select	`GRATING`
Wavelength Select	`WAVELENGTH`
Camera Shutter	`OPEN, SHUT`

Commands and arguments need only be entered to as many characters as make them unambiguous. For a list of commands and brief description of each, type `HELP`. To list valid arguments for commands enter the command followed by a `?` and hit a return. Example `LFW ?` will list the available filters in the lower filter wheel.

3.3.1 Examples of Setting up the Spectrograph

1. Set the grating turret to the 832 gpm: `GRATING 832`
2. Set the central wavelength to roughly 4400 Å. `WAVE 4400`
3. Set the lower filter wheel to clear: `LFW CLEAR`
4. Set the lower filter wheel to dark: `LFW DARK` or `DARK`
5. Set the upper filter wheel to L-42: `UFW L-42`
6. Set the TIRP to 1.80: `TIRP 1.80`

7. Set the apertures: APERT $1''$x$3''$

8. Open the shutter about 10% of its area: OPEN 0.1

9. Open the shutter all the way: OPEN (Only do this when the chamber lights are off, the sky is dark, and you have verified that no bright object is in the apertures.)

10. Make the Spectrograph Safe to Slew to a New Object: DARK

11. Make the Spectrograph Safe for Chamber Lights: SAFE

12. If the zero point in the relation between wavelength and grating tilt is incorrect, the displayed central wavelength will be wrong. To fix this, first find a wavelength-pixel pair near the center of the scan, e.g. 4510 at pixel 2205. Issue the command: ZERO 4510 2205

    The grating may now be re-centered, if desired, with the WAVE command. The former command assumes that the pixel value runs from 0 to 4096 (i.e. 8k mode). If you are working in 4K mode, issue the command: BMODE 4K

13. To save the current status as a set-up issue the command STORE and then give a setup name and comment when queried. To list the existing setups, use LIST. To invoke an old setup, type the setup's name. Note that the camera shutter is always closed immediately upon execution of a setup.

3.4 Observing Procedures

3.4.1 Description of the Data-Taking System

The counts coming from the discriminator electronics are stored in two memory banks of 4096 16-bit words, hereafter referred to as the "integration buffer". One bank is for the left channel and the other is for the right channel. Each memory address stores the counts from 1/4 of a 25 μ Reticon diode. It is important to realize that these memories are external to the instrument computer, so that if the computer should crash, data residing in the integration buffer are not lost.

A sophisticated Forth operating program running on the Point 4 enables the user to take the data, display it, store it, and partially reduce it. A single keyboard can serve both the Point 4 and BCCS systems or the observer can opt for separate keyboards.

In the following sections all Forth commands typed on the console are presumed to be followed by a return. Commands **not** taking a return are flagged `(no cr)`

All data to be read, stored, or otherwise manipulated, whether coming from the integration buffer or retrieved from the Trident Disk, passes through an area of memory in the Point 4 computer referred to as the "scratch buffer". Because of limited memory, this buffer consists of only 4096 words. Thus, in order to display both the left and right contents of the integration buffer at once, the 8192 words must be compressed (by adding together the data in words 1+2, 3+4, ...) to yield 4096 words,resulting in a slight loss of sampling in the display. The option also exists to display separately either the left or right arrays. These options are controlled by an integer named `?BANK` as follows:

`0 ?BANK !` sets `?BANK` = 0 (for left array display)

`1 ?BANK !` sets `?BANK` = 1 (for right array display)

`2 ?BANK !` sets `?BANK` = 2 (for compressed left and right display)

`?BANK ?` displays the value of `?BANK`.

Note that 2 is the default value of `?BANK` and `?BANK` is automatically set to 2 whenever the system is restarted and when data are stored from the integration buffer to the disk.

The full left and right arrays may be automatically stored on the disk in two files of 4096 words each or in a single compressed file of 4096 words. These two storage modes are referred to as the "8K" and "4K" modes, respectively. The mode currently in effect is indicated at the extreme right of the third line of the banner displayed on the instrument computer monitor. To switch from 4K to 8K type `8K` and conversely. If the 1.0 arc-sec slit or image stacker is used, the 8K mode is recommended, otherwise significant resolution will be lost. Since the uncompressed mode involves pixels of 1/4 of a Reticon diode, this mode is also referred to as "quarter-diode" mode; the compressed mode is sometimes referred to as "half-diode" mode.

Whenever one of the data files (always consisting of 4096 words) is read back into the scratch buffer from the disk for display or manipulation, the 4K/8K mode or the value of `?BANK` is irrelevant– whatever is stored in that 4096-word file is displayed from the 4096-word scratch buffer.

3.4.2 Trident Disk and Data File Organization

Data are stored on the Trident Disk and may be subsequently or simultaneously stored on magnetic tape. The disk is organized into blocks of 31 4096-word files. A block will subsequently be referred to as a data 'directory'. Thus, each directory holds 31 exposures in the 4K mode and 15 exposures in the 8K mode. That is, when storing in the 8K mode the left side of exposure #1 is in file 1, the right side of exposure #1 is in file 2, left side of exposure #2 is in file 3 ..., right side of exposure #15 is in file 30, and so on. Directories are numbered sequentially, and the numbering scheme continues even when disk packs are changed, so that a given pair of directory and file numbers uniquely labels any observation. When data are sent to or from the disk, the Point 4 must be "linked" to the correct directory. This is done by the command `NNNN TLINK` where `NNNN` is the directory number. After executing this command the system asks whether that directory is the directory into which you wish to store data. If so, the command `?DISK` should be executed. After executing this command, a subsequent `MMMM TLINK` command (where `MMMM` is some other directory number) which is *not* followed by the `?DISK` command will enable you to read from directory `MMMM` but storage commands will still correctly store the data in directory `NNNN`.

When a directory has been filled with 31 files, the system will automatically link to the next directory. If, however, one is working in 8K mode and the last file stored was file number 30 in the current directory, the left half of the next file stored will go into file 31 and the right half will go into file 32. This is not particularly upsetting to the control program, but if it upsets your sensibilities, manually `TLINK` and `?DISK` to the next directory before the file is stored. To find the current directory into which you should start storing data at the beginning of your run, consult the *Reticon Data Log/Current* blue notebook. Please remember to enter all data which is stored on the disk in the data log notebook.

To list the contents of the current directory, type `DIRS`.

Each physical disk pack stores 120 directories. When the disk is full a new one must be mounted. This will normally be done by the Instrument Specialist. Please alert the MMTO staff before you attempt to change disk packs.

3.4.3 Commands for Starting, Stopping and Storing Integrations

ZGO — sets the integration buffer to zero and begins integrating. The display on the monitor will indicate the total number of counts on each channel, will indicate that the status is *Integrating* and that the time left is *Forever* since no command has yet been given setting the length of the integration. ZGO automatically executes an RCOMMENT (see below) which gets telescope coordinates and puts you in the Comment field.

ZABORT — is a safety feature incorporated into the system to remind users that the integration buffer is going to be reset to zero. If the command ZGO is given and the present contents of the integration buffer have not been stored, the system will type *No Erase!* If you are sure that you do wish to erase the unstored contents of the integration buffer by setting the buffer words equal to zero, then you must precede ZGO by ZABORT. There are several higher-level forth commands which must be preceded by ZABORT. In that case simply type ZABORT FLATFIELD, e.g.

NNN TOTAL — defines the length of the integration in seconds, where NNN is any integer, and it also automatically stores the result on the Trident disk (and on magnetic tape if the autotape option is selected). TOTAL also accepts sexigesimal input; i.e. 15:00 TOTAL specifies an integration time of 15 minutes.

GO, STOP — These two commands simply start and stop the integrations. They do not reset the integration buffer nor do they store the contents of it. The clock measuring the integration time starts and stops but is not reset. These commands are used if you want to stop integrating temporarily (e.g. because of clouds), and then resume integrating when the clouds leave.

HALT — stops the integration and stores the contents of the buffer; use this, for example, if clouds have halted your observation before the integration time specified by your NNN TOTAL command, but there is no hope of resuming and you wish to store what has already been accumulated. If for some reason you want to execute HALT, thus stopping the integration time clock, but you do **not** wish to store the contents of the integration buffer on the disk, then use HELP HALT.

OZGO — (Only-ZGO) clears the integration buffer and starts an integration without performing an RCOMMENT. This word is handy during instrumental setup. We discourage its use during actual observing.

In summary:

- ZGO — zero the buffer and start an integration.

- `ZABORT ZGO` — zero the buffer and start an integration (required when previous contents of integration buffer not stored).
- `NNN TOTAL` — integrate for a total of `NNN` seconds and then store the results.
- `STOP` — temporarily stop accumulating counts in the integration buffer; stop the integration time clock.
- `GO` — resume accumulating counts; restart the clock.
- `OZGO` — clear the buffer and start an integration; no `RCOMMENT` performed.

3.4.4 The Comment Field

The Comment Field is a block of text which can be written into each data file and which generally contains such valuable information as spectrograph configuration, object coordinates, and other observer comments. The observer is encouraged to fill out the comment field for all of his/her data files as they are being recorded. This is of importance not only for the integrity of the data, but also for the purpose of spectrograph maintenance.

The Comment Field is organized by the Comment Template, a block of text into which the observer can enter information. The Comment Template can be changed and, in fact, has been changed at various times in the past.

When an integration is initiated, the top row of the computer display shows that the integration has no name (*no-id*) in the object field. In addition, a *C* will flash next to the no-id message indicating that the current integration has not had its comment field edited. Successful editing of the comment field will cause the text entered into the object field of the comment block to be inserted into the object field of the computer display and the flashing *C* will disappear.

Failure to edit the comment block will result in no comments being stored in the field. The software does not automatically enter the current comment block into a new file. The following commands are used to edit the comment block:

`COMMENT` — Typing this command will cause the regular display to disappear and be replaced by the comment template as last edited, with the cursor positioned at the first field. If you reach the end of the field while typing, the cursor will jump to the next field. The special characters listed below allow one to move from field to field with relative ease. When the comment field is filled out satisfactorily, type `Ctrl-X` to exit from the comment mode. The computer will then prompt you to confirm the modifications to the comment field. Hitting a carriage return will cause the computer to record the comment field into the file created when the current integration is stored; an Esc will abort the comment editing.

Special Keys Used in Editing the Comment Block

- `Return` — moves the cursor to the first unprotected field of the current line, or to the first field of the next line if already at the beginning of the line.
- `Esc` — Moves the cursor to the next unprotected field, or to the beginning of the next word in the current field
- `Line Feed` or `Ctrl-J` — Moves the cursor to the first unprotected field of the previous line.
- `Tab` or `Ctrl-I` — Moves the cursor to the previous unprotected field.
- `Backslash` — Moves cursor forward a space without changing the traversed character.
- `Delete`, `Rubout`, or `Backspace` — Moves the cursor back one space without changing the traversed character.
- `Ctrl-D` — Deletes the character at the current cursor position.
- `Ctrl-K` — Deletes all characters in the current field.
- `Ctrl-X` — Exits from comment editing mode. To store the comments, hit `Return` (or any character other than `Esc`). To cancel any editing, hit `Esc`.

`RCOMMENT` — This word works precisely the same as `COMMENT` except that the current 1950 coordinates of the MMT are reported to the Instrument Computer via the link between it and the Mount Computer. These are automatically entered into the R.A. and Dec. fields of the comment block. If the link is not established between the two computers, the coordinates will not be reported but one can still enter information into the comment field. Note that `ZGO` now automatically executes an `RCOMMENT` after starting the integration.

n `OLD-COMMENT` — This word updates the comment block of file n in the current directory using the comment file of that file as a starting point. Use this word if comments have already been recorded for that file and you simply want to correct an entry or two.

n `NEW-COMMENT` — this word updates the comment block of file n in the current directory using the current comment field as the starting point. Use this word if the file did not have any comments recorded.

3.4.5 Storing Data on Magnetic Tape

Data which are intended to be reduced on the UAO MV 10000 system or data in FITS format should be written on tape by following the instructions in this section. All users must provide their own magnetic tapes.

1. Go upstairs to the computer room, and actuate the upstairs TTY using the up/down switch..

2. Mount the tape on the CIPHER tape drive, making sure there is a write-enable ring in the tape. Close the drive door.

3. Turn on the power to the tape drive if it is not already on. Press the Load button. The tape should position itself to the beginning-of-tape mark and the red Load and Write Enable buttons should come on. Select either HIDEN (1600 CPI) or normal (800 CPI). Press the On-line button.

4. If the tape is a new tape or if it is an old one, but it is all right for the old data to destroyed by overwriting, then enter on the upstairs TTY: `MAGTAPE 0 INITIALIZE-TAPE` *xxxxxxx* where *xxxxxxx* is any 7-character string of your choice for ID purposes. If you wish to write a FITS tape, specify `FITS` as the string *xxxxxxx*. The computer will respond with the message: *Escape now or take the consequences! (waiting)...* If you are sure that it is ok to erase any old data on the tape or if it is a new tape, hit the `Return` key. (Otherwise hit the `Esc` key).

   After the `Return` key is hit the system will display the message: *Tape name=xxxxxxx*, where *xxxxxxx* is your ID. If the message *Tape name = xxx still mounted* appears, type `DISMOUNT-TAPE` and repeat this step.

5. If the tape is not a new one and already has data on it that you **do not** want erased then instead of the `INITIALIZE-TAPE` command you should enter: `MAGTAPE 0 MOUNT-TAPE` The system will respond with the *Tape name=xxxxxxx* message.

6. In either case you should then enter `DISCARD` to remove the `MAGTAPE` overlay.

7. There are two ways of writing the data stored on the Trident hard disk to tape:

   (a) At the end of the night or end of the run you may copy entire disk directories to tape. For each such directory you must be linked to the directory you wish to copy (see `TLINK`). The command `ALL-FILES-ARCHIVE` (note the hyphens) will then copy that directory. For example, to copy directory 3872 enter: `3872 TLINK ALL-FILES-ARCHIVE` which will result in system messages (*Copying, Verifying, Done!*) confirming that the data from all the files in that directory have been written. To then write directory 3873 on tape: `3873 TLINK ALL-FILES-ARCHIVE`.

   NOTE: Users who wish to use the UAO MV 10000 reduction system should not use the DIRECTORY-ARCHIVE command which is discussed in the Reticon manual.

   (b) Alternatively, the data can be written to the tape in real time as they are being recorded on the Trident disk. This is the safest procedure though it does waste some observing time. Even though the data written onto the disk have some safeguards against accidental erasure, we have experienced at least one instance of loss of data between the time they were recorded and before the user got around to use the `ALL-FILES-ARCHIVE` command. If the observing program consists of many short duration files, one may wish to avoid the overhead in time of writing the files to tape during the observing. In this case use the procedure outlined above.

   To use the 'autotape' option, enter `AUTOTAPE`. A *T* will then appear to the right of the *Time Left* display. Data will automatically be written to tape every time they are written to disk. To deactivate the `AUTOTAPE` feature, enter `NO-TAPE`.

   Remember that for either option, `DISCARD` must be executed after the `MOUNT-TAPE` or `INITIALIZE-TAPE` commands.

8. A hard-copy of the file names actually written on the tape can be obtained by: `TTY-ON DUMP-TAPE TTY-OFF`. Each individual file on tape will be numbered consecutively.

9. When you have finished with a given tape enter `DISMOUNT-TAPE`. The system will not accept a new `INITIALIZE-TAPE` or `MOUNT-TAPE` command until this is done. If you have previously selected the autotape option, be sure to disable it by entering `NO-TAPE`. Otherwise the data system will hang after storing the next exposure as it tries to write to an unmounted tape.

   Press the On-Line button on the tape drive to take the drive off- line, then hit the Rewind button and remove your tape.

10. Writing a FITS-Format Tape

    As noted above, if you desire a FITS tape, all you need do is to specify the tape name as `FITS` when the tape is initialized (step 4, above). All writing to tape is then handled in a transparent way.

3.4.6 Focusing the Spectrograph

The spectrograph can be accurately focused using the Hartmann focus masks in the Top Box. The following general comments should be noted: In the following we refer to units of travel of the fine focus readout. One unit =.001 inches on the dial — i.e. 50 units is one revolution of the big dial. To the best of our ability to measure, the focus of the spectrograph does not change when different gratings are inserted. However, when filters are inserted in the top and bottom filter wheels underneath the aperture, the focus will change. For example:

To go **from** Clear **to** Copper Sulfate in the top filter wheel add 9 units.

To go **from** Clear **to** L-42 add 5 units.

The focus is quite sensitive to temperature changes. We do know that a change in temperature of the spectrograph of as little as five degrees Centigrade will effect the focus. The Hartmann procedure is easy to carry out and very accurate. We suggest that observers periodically monitor the spectrograph temperature using the readout in the instrument support rack. See section 3.1.2 for instructions on reading the temperature. Should the temperature vary by more than about 5° C, check the focus with a Hartmann test.

The Hartmann Focus Test

1. Select the appropriate grating. Put the spectrograph into slit (non-stacker) mode.

2. Select a grating angle in a fairly rich part of the spectrum (e.g. about 4500 Å for the 832 gpm grating).

3. Set the Hartmann wheel to the L-HART position.

4. Insert the order-blocking filter if you plan to use one.

5. Set ND filter in Top Box. A good result is obtained with about 200 counts/side/s with the 832 gpm grating at 4500 Å. This is slightly above the illumination guideline.

6. Select the 1×3 arcsec aperture.

7. Start an integration. This is an occasion where the word `OZGO` is appropriate.

8. Insert the comparison mirror and turn on the He-Ar lamp, checking that the count rates are safe.

9. Execute the following software commands:

   `O ?BANK !`

   `4.0 SIGMA .!`

   `HARTMAN` (with one final `N`)

   `L-HART`

10. The program asks *Do you want to store files?* Type `N (no cr)`. The program then says *Mask off left side, hit key when ready.* If you have already put the Hartmann wheel in the L-HART position, hit `Return`. When the integration of 90 seconds is over, change to the R-HART position. Then type `R-HART`.

    The program will again say *hit any key when ready.* Hit `Return`. After 90 seconds the results of the Hartmann test will be displayed on the terminal. Enter `TTY-ON PRINT-SHIFTS TTY-OFF` to get a hard copy.

    The average of the left channel and right channel values are printed out at the bottom of the printout, and are labeled *Left Mean* and

Right Mean. These refer to the first and last halves of the left Reticon array since ?BANK = 0, not the entire left and right arrays.

11. The correct focus is then given by: True Focus = Current Focus + C$\times\mu$, where C is a constant which is about 12.0 and μ is the average of *Left Mean* and *Right Mean*. The current value of C is normally recorded on the whiteboard in the control room. See Section 3.2.1 for instructions on adjusting the spectrograph collimator focus. If you are badly out of focus, the line-finding software may fail. In this case, plot line width vs. focus, without the Hartman mask.

    Some curvature of the focal plane may introduce an apparent systematic focus change between the two halves. The right Reticon array can be checked by setting ?BANK = 1 and performing another Hartmann test.

12. A second test may be performed at the new focus setting. A net residual μ of ± 0.2 or 0.3 pixels is adequate. Type `DISCARD` to remove the Hartmann focus software overlay. You may also want to reset ?BANK to its previous value.

This completes the Hartmann focus procedure. Typical line widths for the 1×3 arcsec slits and Image Stacker are 4 and 3.5 quarter-diode pixels (FWHM), respectively.

As an example, consider the case where the Hartmann procedure was carried out, resulting in a *Left Mean* of -2.5 and *Right Mean* of -1.9. This yields $\mu = -2.2$ and, assuming C = 12, implies that we are -26.5 units away from the true focus. If the current focus reads 821, we then simply decrease the reading to about 795. Repeating the Hartmann procedure will verify that we are now in focus.

3.4.7 Calibration of the Total Internally Reflecting Prism (TIRP)

The TIRP can be remotely rotated about the optical axis of the spectrograph so that the spectrum is shifted by a small amount perpendicular to the dispersion direction. The purpose of this adjustment is to ensure that light passing through the left aperture falls only on the left Reticon array and not on the right array. Each grating requires a separate setting; in addition, since the gratings are not always in the same turret positions, a setting for each run must be determined. In addition, there is a small wavelength dependence for the optimum TIRP setting for a given grating; if you change the setting by a large amount (e.g. ~ 2000 Å for the 832 gpm grating), you should determine a new TIRP setting.

Normally the TIRP is calibrated each time a grating is changed, that is, each time it is physically removed from the turret, not just swung into place. The optimum settings are recorded on the whiteboard. Normally these settings suffice, however, if you are at all uncertain about the TIRP calibration, proceed as follows:

1. Select the grating turret position and grating angle you wish to use.

2. Select the 3 arcsec single circular aperture.

3. With appropriate ND filtering (start with ND 2.0 and then drop back), insert the comparison mirror, type `OZGO` and turn on the DIM continuum lamp. Make sure you are well under 2000 counts/side/s.

4. Adjust the TIRP setting until the left and right count rates approximately balance (10% is quite adequate). [N.B. When the 300 gpm grating is in turret position I, it cannot quite be balanced, but at the limit of the TIRP it is close enough.] Do not expect the balance to hold on a pixel-by-pixel basis. Do not be alarmed by the noisy, notched appearance of the spectrum: S-distortion in the spectrum and defects at the junction of the split boole are responsible. When the sky-star apertures are used, they are ~ 32 arc-sec apart, which projects to a separation of ~ 0.5 mm at the split boule face; the S-distortion is much smaller than this.

5. Record your value on the whiteboard with a marker pen if the value for that grating has not been recorded for the current run.

3.4.8 Wavelength Calibration

Exposures of comparison sources can be carried out using the command `CEX`, which initiates a ninety-second exposure. To change the default duration see the *CfA Reticon Manual*

Below 3480 Å, the He-Ar lamp is very sparse. If you need good wavelengths below this it is suggested that you also use the Hg-Cd lamp. This lamp has been filtered with a U-330 filter which drastically attenuates longward of 4000 Å although some lines are still visible. The following procedure is also used by some observers:

1. During the day insert the U340 filter and CuSO4 filter

2. Set the ND wheel so that the brightest lines have count rates less than 2 counts/s per 8K pixel.

3. Take a long He-Ar-Hg-Cd exposure and record it. This will give you 3480 and 3187 and several other short wavelength lines.

4. Turn off the lamp, remove the U340.

5. During the night take short exposures with suitable ND and without U340: A small zero point shift can be applied to your distortion curve obtained during the long exposure. Note that this assumes 0th order shifts only. It is indeed the case that higher-order terms also change with flexure, so if high wavelength precision is required, longer comparison integrations should be performed.

3.4.9 Suggestions Concerning Flatfield Calibration

Long (several hour duration) flatfield exposures are normally done in afternoon before observing and during the morning afterward. Make sure that the building flashers are on during flatfield integrations. Flatfields are normally terminated by the day crew at around 09:00 to 10:00. Leave a note for them if you need to go longer.

Start flatfields with the command `ZABORT n FLATFIELD`. This will commence a series of exposures of n minute duration, which will repeat forever. To stop the series, storing the current integration, type `NOREPEAT HALT`. To stop the series, discarding the current integration, type `NOREPEAT HELP HALT`.

1. For the 832 shortward of 4000 Å, remove the copper sulfate filter (with suitable ND!) and use 1st order.

2. For the 1st order gratings at wavelengths shortward of about 4000 Å, you may wish to do two sets of incandescents, one at your nominal grating setting and one with the grating displaced to longer central wavelengths. The efficacy of this procedure has not been established.

3.4.10 Night-Time Observing Procedure

It is assumed that the system is performing satisfactorily and that the spectrograph has been focused. It is recommended that wavelength calibration and flatfield exposures be taken during the afternoon preceding the evening observations. You must, of course, record this data on the hard disk for later processing.

Be sure that the Telescope Operator understands when you want the building shutters opened. Never have the image tube high voltage on and the camera shutter open without turning on the warning flashing light. Be very careful of excess illumination in the building during the day when the comparison mirror is OUT and the camera shutter is OPEN.

It is recommended that the top box shutter be closed when the building shutters are opened. It should be opened only when the sky has dimmed sufficiently to start observing. Those observers requiring twilight sky integrations should open the camera shutter slowly while monitoring the count rates.

The first step in the evening observing routine will normally be for the operator to find an SAO star near your first object to check the telescope pointing, focus, and the coalignment of the mirrors. **BEFORE ANY SAO STAR IS ACQUIRED, BE ABSOLUTELY SURE THAT THE LOWER FILTER WHEEL IS IN THE DARK POSITION. IT IS RECOMMENDED THAT THE CAMERA SHUTTER REMAIN CLOSED UNTIL THE SAO STAR IS REMOVED FROM THE FIELD.**

The second step may be to observe a standard star if the spectral energy distribution of your program objects is desired. Objects brighter than 14th magnitude for the 832 gpm and 15th for the 300 gpm gratings will generally be too bright unless the 1.25 or 2.5 **magnitude** neutral density filters in the lower filter wheel are used, or unless the images from fewer than six primaries are observed at a time.

Program objects may then be observed. The normal procedure for both standards and program objects is to observe for N minutes with the star in the left aperture and then N minutes in the right aperture, though some observers prefer a sequence of left N minutes, right 2N minutes, left N minutes which eliminates linear temporal variations in the sky brightness. Brief (90 s) wavelength calibrations should be interspersed every 20 minutes or so, or more often if high precision is desired.

3.5 On-Line Display and Partial Reduction of Data

A spectrum of 4096 pixels can be plotted if and only if it is residing in the scratch buffer. These 4096 pixels may represent just the left or right channels or both left and right channels depending upon whether the 4K or 8K mode was utilized.

3.5.1 Moving Data from the Integration Buffer to Memory

At any time during an integration, you may move data from the integration buffer into the scratch buffer without disturbing the ongoing integration. Whatever was previously in the scratch buffer will be overwritten. The command for this is `DMOVE`.

3.5.2 Reading, and Manipulating Data

Suppose you wish to read file 17 from directory 3872 into the scratch buffer. If you are already in directory 3872 then `17 RFILE` will accomplish this. If you are not in the directory, execute `3872 TLINK 17 RFILE`

Data may be added to or subtracted from data already existing in the scratch buffer, e.g. if you were in directory 3872, `31 RFILE 3873 TLINK 1 +FILE 3 +FILE` will read file 31 from directory 3872 and add to it files 1 and 3 from directory 3873.

3.5.3 Commands to Plot Spectra

`ERASE` —Erases the Grinnell screen.

`n1 n2 PLOT` — Plots the data in the scratch buffer from pixel n1 to n2. If n1 and n2 are omitted, an error message results.

`n1 n2 EP` — Erase, then plot from n1 to n2

The plotting routine scales the data for plotting in such a way that the maximum and minimum values will be plotted. Occasionally it is desirable to plot just a narrow swath in the y coordinate. To do this:

`1 SSW !`

`X1. X2. Y1. Y2. PSET` (note decimal arguments)

`X3 X4 EP`

The program will then re-plot the data, re-scaled so that the y-axis runs from Y1 to Y2. The x-axis will be **labeled** from X1 to X2 but the data **plotted** run from X3 to X4. To restore the normal autoscaling enter the commands `0 SSW !`

3.5.4 Sky Subtraction

Recall that in 4K mode, each disk file contains both the object+sky and the sky spectrum with the data taken through the left aperture first. In 8K mode these two spectra are written in the same order but in two separate files. This necessitates different procedures for sky subtraction.

4K Data

If S1 is a file containing the spectra obtained from an observation with the object in the left hole, and S2 contains those from an integration through the right hole, the sky-subtracted sum of these two observations can be formed and plotted by typing `S1 RFILE S2 -FILE L-R 0 2047 EP`

If S3 and S4 are the next two integrations on the object through the left and right holes, respectively, the sky-subtracted sum can be formed and plotted by typing: `S1 RFILE S2 -FILE S3 +FILE S4 -FILE L-R 0 2047 EP`

The spectrum is left in the scratch buffer. L-R subtracts the data in pixels 2048-4095 from that in pixels 0-2047.

8K Data

Sky-subtracted sums may be generated as follows: Let S1, S2, S3,... be the numbers of the files containing the object+sky and K1, K2, K3,... be the numbers of the files containing just the sky, regardless of whether the star aperture was the left or right aperture. Then: `S1 RFILE S2 +FILE S3 +FILE ... K1 -FILE K2 -FILE K3 -FILE ...` will leave the spectrum in the scratch buffer from which it can be plotted.

3.5.5 Establishing a Linear Wavelength Scale

The distortions in the image tube are large enough that there are large departures from linearity in the pixel-wavelength relation. Several users have requested instructions to apply a linear wavelength calibration, however. The following discussion explains how to do this.

Suppose you want to map the data onto any wavelength interval in the larger interval 4000 Å to 6000 Å. You must first set two constants, W1 and W2, as follows: `4000. W1 .! 6000. W2 .!` (note the required decimal points).

You then need two wavelength-pixel pairs: WA, PA and WB, PB which you get from looking at the result of a comparison exposure and finding the pixel positions of two lines of known wavelength. These should be well separated with WA close to W1 and WB close to W2. Let us say that He I λ3889 occurs at pixel 200 and λ5876 at pixel 1800. Mapping commands only work in 4K mode, so if your spectra cover 4096 pixels, use `2SUM` to squash them into 2048 pixels.

The command: `3888. 200. 5876. 1800. SWL` will generate a first-order wavelength fit. Once this is done, one can map any spectrum into wavelength space.

The command: `WMAP` will re-bin the data in the scratch buffer so that pixel 0 is at wavelength 4000 Å and pixel 2047 at 6000 Å. The commands: `ERASE LAM1 LAM2 WPLOT` will erase the screen and plot the calibrated spectrum between wavelengths `LAM1` and `LAM2` (where `LAM1 > W1, LAM2 < W2`, and `LAM1` and `LAM2` are floating-point numbers).

Summarizing, at the beginning of the night execute the following procedure:

1. Read a comparison exposure into the scratch buffer. If was taken in 8K mode, execute `2SUM`

2. Decide on values for W1 and W2; determine two wavelength-pixel pairs; and execute:

   ```
   4000. W1 .!
   6000. W2 .!
   3888. 200. 5876. 1800. SWL
   ```

3. To map the data in the scratch buffer and plot it between, for example, 4500 and 5500 Å:

   `2SUM` (if data are in 4096 pixels per spectrum)

   ```
   WMAP
   ERASE
   4500. 5500. WPLOT
   ```

3.6 Use of the Echellette Grating

The echellette grating is a 6 × 10 inch 240 gpm grating custom ruled for the MMT Spectrograph by Hyperfine Inc. It was designed for use in orders 6 through 17 with cross dispersion provided by the large 45 degree apex angle quartz prism housed inside the spectrograph. In this mode the grating would yield full coverage from about 3100 to 8000 Å at a resolution of about 30 km/s. However, since the prism cross disperser produces curved orders and since we do not have a two-dimensional detector, the echellette can only be profitably used with order-sorting filters.

The properties of the echellette are described in the table below. Filter transmission curves can be found in the Appendix D.

Order	*Short* Å	*Center* Å	*Long* Å	*FWHM* Å	*Filter?*
8	6318	6713	7107	789	y
9	5653	5967	6318	665	y
10	5114	5370	5653	539	y
11	4670	4882	5114	444	y
12	4296	4475	4670	374	y
13	3978	4131	4296	318	y
14	3704	3836	3978	274	y
15	3465	3580	3704	239	$< 50\%$
16	3254	3356	3465	211	n
17	3068	3159	3254	186	n

The echellette is very straightforward to use if you keep one thing in mind: almost all wavelengths of interest can be observed at a single grating setting. That is, the angle of use of the grating is the same for all orders and, with the exception of the lowest orders, the free spectral range of the grating (or the width of the filter) is smaller than the bandpass observable by the detector. The means of changing wavelengths (once one has the grating on blaze) is simply to change filters. The SCCS computer should then be informed of the new order and the central wavelength can be tweaked.

The following examples should suffice:

1. To set up the echellette in, say, 9th order, centered at 5900 Å, issue the following BCCS commands:

   `GRAT ECHELLETTE`

   `ORDER 9` (always set the order before the central wavelength)

`UFW 9TH ORDER` (assuming the filter is in the upper filter wheel)

`WAVE 5900` (at this point the grating tilt will be driven)

`TIRP 3.70` (get TIRP setting from the white board)

2. To change to 8th order:

   `ORDER 8` (central wavelength will now read 6638)

   `UFW 8TH ORDER`

3. To then center 6700 Å:

   `WAVE 6700` (tilt will be driven)

3.7 The Overillumination Sensor

The overillumination sensor monitors the counts of each Reticon array at all times. Should the count rate of either side exceed 6000 counts/side/s or should the red panic button on the Observer's Paddle be depressed, the system leaps into action, performing the following functions:

1. An attempt is made to grab the bus of the motor control computer. If this is accomplished, the lower filter wheel is driven to Dark. Under normal circumstances, this takes about two seconds. If the SCCS is active when the overillumination alarm goes off, for example, opening the shutter, the overillumination system will not be able to grab the bus and the wheel will not turn.

2. The Top Box shutter is closed. This takes about two seconds.

3. If the overillumination persists for more than about six seconds, power to the image tubes is shut off. **THIS SHOULD BE AVOIDED.** Dropping the power precipitously is hazardous to the continued health of the image tubes.

Should the alarm be triggered the following steps should be carried out:

1. *Determine the source of the overillumination and remove it.* Assuming that the power to the tubes was not shut down, proceed as follows:

2. Ask the operator to open the top box shutter. Verify that no bright star is in the apertures.

3. Reset the lower filter wheel. This is a bit tricky. When the bus is grabbed and the lower filter wheel is driven to Dark, the control program is not informed. Therefore, BCCS thinks that the wheel is at the same position as it was before the overillumination occurred. To re- synchronize it with the wheel, type `LFW DARK`, and then drive it to the position desired for observing.

The overillumination system is not foolproof. We can (but will not) describe plausible scenarios where the system will not be able to block the source of illumination in time to avoiding crashing the tubes. Do not be lulled into a false sense of security by its presence.

Chapter 4

Operation of the Spectrograph — The Red Channel

4.1 CCD Performance

4.1.1 Readout Noise

The readout noise of the CCD is 7 ± 1 electrons.

4.1.2 CCD Gain

The gain of the CCD is 2.6 electrons per digital unit (ADU).

4.1.3 CCD Orientation

The CCD is oriented such that the vertical transfer direction is perpendicular to the dispersion. In the common parlance this means that the dispersion direction is oriented along a *row* and the spatial dimension is along a *column*.

4.2 Detector System Components and Their Locations

4.2.1 CCD Dewar

The dewar is the red cylindrical object jutting out of the bottom of the North side of the spectrograph at an odd angle. There are no user-servicable parts to the dewar, so do not touch it or its attendent electronics.

Filling the Dewar

Normally there is no need for the observer to fill the dewar with liquid nitrogen. In fact, we would prefer it if you would not; instead leave the job for the MMT day crew or the Telescope Operator.

You should only fill the dewar if the following three conditions are met:

1. The CCD temperature is rising above its nominal value of -141° C.

2. It has been more than 12 hours since the last dewar fill (as noted on the Telescope Operator's clipboard.)

3. There are no qualified MMTO staff members on the mountain.

If these are the case, call the Instrument Specialist or Instrument Scientist for instructions (Appendix E).

4.2.2 CCD Camera Head Electronics

The camera head electronics box is the gold box attached to the dewar. Please do not open it, or disconnect or jiggle any of its cables.

4.2.3 CCD Interface Box

The interface box is mounted on the east side of the Blue Channel. The box has on it a rotary switch and an LCD readout with which one can monitor the CCD power supply voltages and chip and dewar temperatures.

4.2.4 Shutter

The shutter is mounted on an arm which extends into the body of the Blue Channel from the South side. During Blue Channel operation it is cranked out of the way using a crank mounted on the side of the spectrograph. It is inserted into the beam during Red Channel installation. There is no need for the observer to move this crank under normal circumstances.

4.2.5 Camera Controller and Power Supplies

The CCD controller and power supplies are two black chassis mounted in the instrument computer racks in the computer room. The controller is mounted above the Grinnell and the power supplies are to the left of the Grinnell, under the writing surface. Under normal circumstances the user should not need to touch these systems. Should the need to power the system down arise, however, first turn off the Controller, then the power supplies. Power up in reverse order, that is, first turn on the power supplies, then the Controller.

4.3 Manually Operated Functions

4.3.1 Cross-Dispersion Prism Insertion

The prism is inserted into the beam using the crank mounted on the East side of the spectrograph on the prism housing. Normally the prism will be inserted or removed by MMTO staff. Turning the crank clockwise *removes* the prism from the beam.

4.3.2 Camera Angle Rotation

The camera angle rotation is locked by the allen-head cap screws on the flange around the prism housing. Since this assembly is not counterbalanced, loosening the screws will cause the camera and dewar assembly to swing free — an action to be avoided. The camera angle should only be changed by properly-trained MMTO personnel. If you have a need to be trained, e.g. you will be changing from non-cross-dispersed to cross-dispersed modes many times during the night, contact the Instrument Specialist.

At one limit of its travel the camera box is limited by a non-adjustable stop. This is the position for non-cross-dispersed work. At the other limit the box is constrained by an adjustable stop set by a micrometer mounted on the North side of the spectrograph. This is the cross-dispersed position. Nominal settings for the micrometer are given in section 4.7.2.

4.4 RCCS Examples

The SCCS system is described in detail in the *BCCS/RCCS/ECCS Manual*. The following examples illustrate all of the commands needed to configure the spectrograph and should suffice for the novice user observing at the telescope (i.e. not remote). We assume that the Top Box is being run by the Observer's Paddle.

The functions which can be controlled and commands that control them are:

Function	*Command*
Aperture Wheel	`APERTURE`
Upper Filter Wheel	`UFW`
Lower Filter Wheel	`LFW`
Focus Position	`FOCUS`
Grating Select	`GRATING`
Wavelength Select	`WAVELENGTH, ANGLE`

Commands and arguments need only be entered to as many characters as makes them unambiguous. For a list of commands and brief description of each, type `HELP`. To list valid arguments for commands enter the command followed by a ? and hit a return. Example `LFW ?` will list the available filters in the lower filter wheel.

4.4.1 Examples of Setting up the Spectrograph

1. Set the grating turret to the 270 gpm: `GRATING 270`
2. Set the central wavelength to roughly 6200 Å: `WAVE 6200`
3. Set the lower filter wheel to clear: `LFW CLEAR`
4. Set the upper filter wheel to LP-495: `UFW LP-495`
5. Set the focus to 5.3: `FOCUS 5.3`
6. Set the apertures: `APERT 1.5″× 3′`
7. If the zero point in the relation between wavelength and grating tilt is incorrect, the displayed central wavelength will be wrong. To fix this, first find a wavelength-pixel pair near the center of the scan, e.g. 5076 at pixel 205. Issue the command: `ZERO 5076 205`

The grating may now be re-centered, if desired, with the `WAVE` command. The former command assumes that the pixel value runs from 0 to 400 If you are not binning in the dispersion direction, issue the command: `BMODE 800`

8. To save the current status as a set-up issue the command `STORE` and then give a setup name and comment when queried. To list the existing setups, use `LIST`. To invoke an old setup, type the setup's name.

4.5 Using the CCD

4.5.1 Description of the Data-Taking System

The 800 × 800 TI CCD detector of the Red Channel is run by a programmable CCD Controller of KPNO design. The latter is interfaced to the Point 4 instrument computer via a parallel interface. Frames are stored on a small-capacity Diablo disk drive and can be subsequently displayed on the instrument computer's Grinnell. Data are then written to magnetic tape in an internal format.

The software package allows the user to perform noiseless coaddition on readout, binning rows and columns by independent and arbitrary integer values. The binning mode can be set by software.

Limited image manipulation including row and column plots and some frame arithmetic are possible.

The controlling software is somewhat fragile. Users would be well-advised to limit their forays into the the more complicated areas while long integrations are in progress in order to minimize data loss.

As described in section 1.5, the user can select between using two keyboards (one talking to the Instrument Computer, and one talking to the spectrograph control program, RCCS), or one keyboard whose output can be directed to either computer. In the case of the Red Channel, we discourage the use of two keyboards and assume that the user is communicating through the IBM PC keyboard in what follows. Remember: to switch between computers, hit function key F1 on the PC keyboard.

The system is amenable to use from the downtown remote observing room. Remote observers will *not* be able to use the programmed function keys (see section 4.5.14) or the cursor keys in joystick mode (see section 4.5.8).

Data tapes are written in an internal format which is described in the *Steward Observatory CCD Manual.* A facility for translation of these tapes directly to FITS format exists on the Steward Observatory MV 10000 computer. Furthermore, Alan Koski of Steward Observatory has written an IRAF task to read the tapes directly. The task is written in SPP so that it is portable to all IRAF systems. See Koski to obtain a copy.

In what follows, we assume the computers are booted up. See Appendix D for bootup instructions.

4.5.2 Setting the Binning Parameters

As noted above, the CCD Camera Controller is programmable in the sense that the data can be binned on the chip by independent integers in both directions. That is, not binning in columns and binning by 2 in rows (1×2 binning) produces a frame which is 800 columns by 400 rows; 2×2 binning results in a 400×400 frame.

There are two reasons to bin on the chip: (1) readout noise is reduced since the readout noise is incurred per *read-out pixel*, and (2) substantial data compression results. The latter makes operating the CCD much more convenient since many more frames will fit on disk and magnetic tape.

Optimum binning depends on a variety of factors including: (1) the need for adequate spatial sampling along the slit, and, hence, the seeing; and (2) the slit width. Think carefully about your requirements before selecting a binning mode since it is not possible to mix data binned in different modes on the disk and you will need separate bias frames for each mode.

The CCD Controller can also be set up to only read columns within a range of columns. Since the CCD is normally aligned with the dispersion running along rows, this may not be an option that you wish to employ.

Setting the Row Binning Parameter

To bin by N rows, type `N VBIN`.

Setting the Column Binning Parameter

To bin by N columns, reading columns C1 to C2, type `C1 C2 N SETUP`.

A typical set up would then be: `2 VBIN 1 800 2 SETUP NEW-DISK`. This will result in 400×400 frames. Note that the `NEW-DISK` sets up the disk for the new frames, creates a few test areas (with picture numbers less than or equal to zero), and *erase all previous data on the disk.* If a tape was loaded before changing the binning parameters, you must reload it with `LOAD-TAPE`, specifying it as an old tape, before attempting to write to it (see below for a discussion of tape writing).

If you have simply rebooted after a crash and have reset the binning parameters to their values before the crash, *do not do a* NEW-DISK, though you will need to reload the tape as an old tape.

Note that a 20-column overscan region (bias region) is attached to all frames independent of the binning mode.

4.5.3 Initialization

The simplest way to initialize the system is to set the binning parameters with VBIN and SETUP and mount a tape on the tape drive. Initialize the disk with NEW-DISK and type INIT. You will be prompted for the date, time, mode (direct or spectroscopic), and chip name. These are used for informational purposes only. Note that the date does not rollover at midnight. Finally you will be prompted for tape information and the tape will be mounted (see the discussion of LOAD-TAPE, below). Since the tape writing depends upon the binning mode, it is important to define the binning mode before typing INIT.

4.5.4 Annotating the Header Information

Information can be entered into the picture header, most of which is displayed on the screen during integration or after STATUS is typed. The format for entering these commands is to enter the command followed by a Return. You will then be prompted with a '.' Enter the appropriate information followed by another return. Commands that change header parameters are summarized in the following table:

Command	*Updates*
LABEL	Picture label
RA	Right Ascension (hh:mm:ss.s)
DEC	Declination (dd:mm:ss.)
FILTER	Filters
DISPERSER	Grating
TILT	Grating angle
APERTURE	Entrance slit
AIRMASS	Airmass
N COMMENTS	Adds comments to picture number N

Information on the filter, aperture, grating, tilt, and mode can be sent directly from the RCCS program to the Point 4 by hitting function key F5 while the keyboard output is directed to the Point 4. Note that this does not work in countdown mode.

To see the results of changing the header parameters type `STATUS`. If an exposure is ongoing, the console will be put into countdown mode (see below). To exit countdown mode, type `Ctrl-S`.

To list the comments of picture N, type `N NOTES`.

4.5.5 Commands for Starting and Stopping Integrations

There are two ways to initiate a picture. The first will prompt you for a dwell (integration) time and ask whether the shutter should open for the exposure or not. The second uses previously-set values of the integration time and shutter status.

Commands of the first kind are:

`N TEST` — Takes a non-permanent picture, i.e. a picture which can be overwritten and which is lost upon reboot, and stores it on the disk in picture area N. Pictures of this type have picture numbers ≤ 0, and have a 'rank' of 1 (see `FILES`, below).

`N POBS` — Takes a permanent picture, and stores it in picture N, where N > 0. Permanent pictures cannot be overwritten without first purging the existing picture and are not (usually) lost upon reboot. Pictures of this type have a 'rank ' of 2 upon creation and are updated to 3 following writing to tape.

`OBS` — Works the same as `POBS` except that the picture number is automatically incremented from its previous value.

The second way to initiate an exposure is to set the shutter status and integration time and then start the integration. The relevant words are `SHUTTER`, `DWELL`, and `GO`. None of these take arguments; you will be prompted for shutter status and integration time. `GO` starts the integration.

The integration begins by flushing the chip; the shutter then opens and the integration begins. The console will enter countdown mode, in which the integration time is displayed in the lower right corner of the monitor. If you are extremely bored (or wish to become so) you can now simply watch the seconds go by. If not, you can exit countdown mode by typing `Ctrl-S`. You will then be able to interact with the computer, displaying previously-taken pictures, etc. Integration continues in the background and when the exposure is finished, it will be read-out, wresting the control of the computer from you.

If, during an integration, you wish to return to countdown mode, type STATUS.

While out of countdown mode, several words can be used to control an ongoing integration:

STOP — Ends the exposure immediately, writes the data to disk.

ABORT — Ends the exposure immediately, discards the data.

PAUSE — Suspends the integration, closes the shutter. The exposure can then be PAUSEd or ABORTed, or you can continue the exposure with RESUME.

4.5.6 Listing the Pictures on the Disk and Tape

To see a list of the disk picture numbers and their ranks type FILES. To see a list of the pictures on tape, type TAPE-FILES.

4.5.7 Displaying a Frame on the Grinnell

To display a frame on the Grinnell, type N TV, where N is the frame number. To plot two frames, numbers M and N, on the screen, one above the other, type M N 2TV. Picture M will be on top. To plot four frames, the first in the northwest quadrant, the second, northeast, the third, southwest, etc., type M N O P 4TV.

To paint pictures M and N next to each other (M on left, N on right), type M N 2VT; to paint pictures M, N, O, and P, M N O P 4VT.

The Grinnell displays only 512×512 pixels. To look at a larger frame, you must omit pixels with N DECIMATE. For example, 2 DECIMATE causes the omission of every other pixel in both directions, allowing the display of an entire unbinned frame.

To display less than the full frame, set the amount of zoom with N ZOOM, where N is an integer.

To recenter a picture (after zooming in joystick mode, for example), type RECENTER. To reset the decimate and zoom parameters to unity and recenter the picture, type CTV.

The Grinnell only displays 8 bits of data and does not recognize the sign bit. Two commands are useful for windowing the input sixteen-bit signed input data into the Grinnell: N OFFSET adds the integer N to all pixels before display. This is useful if you have negative numbers. `N SHIFT` shifts the data by N bits before output to the Grinnell. The shift is in the direction that positive shifts introduce bits with more significance; negative shifts, less significance.

4.5.8 Joystick Mode

Once a picture has been painted onto the Grinnell, joystick mode can be used to manipulate its display. Type `JS` to bring up the cursor. A small cross will appear in the center of the display. The cross can then be moved with the arrow keys on the IBM PC keyboard's numeric pad. When not using the PC, or when operating from the remote room, the following keys and directions apply:

W	↖
E	↑
R	↗
S	←
D	→
Z	↙
X	↓
C	↘

The numbers displayed across the top of the Grinnell display are the row and column address of the cursor and the data number in the currently addressed pixel (in digital units, *not photons*).

To change the speed of the cursor, use number keys `1` through `9`; where `1` is the slowest (one Grinnell pixel per keystroke) and `9` is the fastest.

Other manipulations which are possible from within joystick mode are described below. All are initiated by control keys.

Ctrl-P	Draws new picture centered on the cursor.
Ctrl-Z	Zooms in on the cursor position.
Ctrl-U	Zooms out from the cursor position.
Ctrl-T	Types the contents of the pixels near the cursor.
Ctrl-I	Performs simple iris photometry about the cursor.
Ctrl-V	Modifies the video look-up table (see CCD Manual). This feature may not be implemented.
Ctrl-R	Plots the current row (see below).
Ctrl-B	Plots an expanded row plot about the cursor.
Ctrl-C	Plots the current column (see below).
Ctrl-Y	Plots an expanded column plot about the cursor.
Ctrl-S	Calculates the mean and standard deviation in a 50×50 square centered on the cursor.

The `Ctrl-S` option is useful for estimating readout noise, etc. To change the default size of the box in which the statistics are calculated, use `N #HIGH !` and `M #WIDE !`, where N and M are the new height and width of the box.

Simply hit a `Return` to exit joystick mode.

4.5.9 Row and Column Plots

Row and column plots can be accomplished from within joystick mode by positioning the cursor at the appropriate row or column and hitting `Ctrl-R` or `Ctrl-C`, respectively. The plot will appear on the Grinnell screen (from which a hardcopy can be made using the Tektronix copier) and can subsequently be expanded by entering joystick mode with `JS`. Relevant joystick commands are `Ctrl-E`, `Ctrl-X`, `Ctrl-A`, `Ctrl-F`, and `Ctrl-N`:

Ctrl-E	Set new upper bound
Ctrl-X	Set new lower bound
Ctrl-A	Set new left bound
Ctrl-F	Set new right bound
Ctrl-N	Replot with new bounds

Plotting is done in 'histogram' style. That is, the limits of each pixel are drawn instead of simply 'connecting the dots'. To plot in the latter style, type `HOFF`. To reinitiate histogram style, type `HON`.

Alternatively, sums of rows or columns can be formed using `RSUM` and `CSUM`. The Syntax for their use is: `R1 R2 N RSUM`, where R1 and R2 are the starting and ending rows (inclusive), and N is the picture number on disk. The summed rows or columns can then be plotted with RPLOT or CPLOT. Therefore, 100 102 4 RSUM RPLOT will sum rows 100, 101, and 102 of picture 4 and plot the result.

RPLOT and CPLOT autoscale the data. To expand a region of interest, use joystick mode or set the boundaries and replot with XMIN XMAX YMIN YMAX NUPLOT where the coordinates are floating point numbers.

To replot the most recent plot, type REPLOT.

Occasionally the computer gets confused and begins to direct terminal output to the Grinnell screen. Should this occur, type INF.

4.5.10 Writing Frames to Tape

Since the disk only holds 5 full-sized (800 × 800) frames, data must be written to tape throughout the night and the frames subsequently purged from disk. There is no automatic way to do this, nor would one want there to be given the length of time it takes to write a frame to tape (several minutes for a full frame). Therefore, one must be conscious of the number of frames on the disk and tape.

Tapes are mounted on the Instrument Computer's Cipher tape drive. Remember to use high density (1600 cpi). At this density each 2400-foot reel will hold about 24 full frames. If you coadd on the chip, the maximum number of frames on a tape and on disk will increase.

To initialize a tape, first specify the tape drive unit number with 0 UNIT, then use the command INIT (see above), or LOAD-TAPE. In either case you will be asked for the reel length, density and a volume serial number. The latter is meaningless. You will then be asked if the tape is a new tape. *Use caution here.* If you specify that it is a new tape and it is not, all data on the tape will be lost (you have hereby been warned).

To then archive frame n from disk to tape, type n TOTAPE. Verify that it has been written to tape by listing those files on the tape with TAPE-FILES. Frame n can now be purged from disk by typing n PURGE.

When writing to tape, one will occasionally get the message ??8. As long as the messages don't persist, ignore them.

To write all frames from picture m to n, type m n TOTAPE-LOOP. To subsequently purge the frames, type m n PURGE-LOOP.

Note that after a picture has been written to tape, its rank which is displayed by FILES is changed from 2 to 3. This is a convenint way to tell which frames have been archived.

To read a frame back from tape, use n `TODISK` where n is the frame number, *not* the sequential number on the tape. To read frames m through n, use m n `TODISK-LOOP`.

To write a scratch picture to tape, one must first create a permanent picture and copy to it. For example, to archive picture -2, we first create a new frame, for the purpose of this example, 10; then we copy to it; then write it to tape:

```
1 10 PCREATE

-2 10 P!

10 TOTAPE
```

Type `REWIND` to dismount the tape and remove the tape from the drive.

4.5.11 Picture Arithmetic

Pictures can be manipulated to some extent using the CCD software. In the interest of the safety of the data, do not manipulate images which have not been written to tape, or first move the image into a scratch frame and manipulate it in situ in the scratch picture. In what follows, DP and SP are picture numbers, X and Y are scalars, and $\longrightarrow$ means that the result goes into the following picture.

SP DP P!	$SP \longrightarrow DP$
SP DP P+	$SP + DP \longrightarrow DP$
SP DP P-	$SP - DP \longrightarrow DP$
SP DP P*	$SP * DP \longrightarrow DP$
SP DP P/	$SP/DP \longrightarrow DP$
SP X DP P*/	$SP * X/DP \longrightarrow DP$
DP X PS+	$DP + X \longrightarrow DP$
DP X PS-	$DP - X \longrightarrow DP$
DP X PS*	$DP * X \longrightarrow DP$
DP X PS/	$DP/X \longrightarrow DP$
DP X Y PS*/	$DP * X/Y \longrightarrow DP$
DP PMINUS	$-DP \longrightarrow DP$
DP PSQ	$\sqrt{DP} \longrightarrow DP$
DP X PMIN	$Min(DP, X) \longrightarrow DP$
DP X PMAX	$Max(DP, X) \longrightarrow DP$

4.5.12 Linear Operations

RSUM and CSUM (see section 4.5.9) put their results in 'descriptors' (vectors) RW0 and C0, respectively; RPLOT and CPLOT plot them. Other vectors exist: RW1, RW2, and RW3; C1, C2, and C3. To move the contents of C0 to, say C2, type C0 C2 MOV. *Be careful to type* C0 *and not* CO (i.e. C-*zero*, not C-*oh*).

Scalar-descriptor operations are possible, as are descriptor-descriptor operations. These are described in the table below. In this table N. is a *floating-point* scalar; it must be followed by a decimal point. D1 and D2 are row or column descriptors.

To plot the result of one of these operations, MOV the resulting descriptor back to RW0 or C0 and plot with RPLOT or CPLOT.

FLOATING N. DINT D1 D2 S+D	$D1 + N. \longrightarrow D2$
FLOATING N. DINT D1 D2 S*D	$D1 * N. \longrightarrow D2$
FLOATING N. DINT D1 D2 S-D	$D1 - N. \longrightarrow D2$
D1 D2 ADD	$D1 + D2 \longrightarrow D2$
D1 D2 SUB	$D1 - D2 \longrightarrow D2$
D1 D2 ISUB	$D2 - D1 \longrightarrow D2$
D1 D2 MUL	$D1 * D2 \longrightarrow D2$
D1 D2 IDIV	$D1/D2 \longrightarrow D2$ (integer divide)
D1 D2 FDIV	$D1/D2 \longrightarrow D2$ (floating divide)

4.5.13 Image Histograms

To calculate a histogram of image m between the data numbers i and j, type i j m HIST. The histogram can be plotted with HPLOT and can subsequently be manipulated in joystick mode. For example, to calculate the histogram of data numbers between 0 and 2000 in picture 3 and plot the result, type 0 2000 3 HIST HPLOT.

To do a faster calculation of the histogram using *every fourth* row, type i j m QHIST.

4.5.14 Function Keys

The following fuction keys on the PC keyboard. All but F1 are defined only when the keyboard output is directed to the Point 4.

F1	Toggle between computers
F2	JS
F3	FILES
F4	TAPE-FILES
F5	Send spect. status to Point 4
F6	OBS
F7	GO
F8	STATUS

F5 updates the disperser, wavelength, mode, and filter fields in the status display. The keyboard output must be directed to the Point 4.

Holding down the `Alt` key and typing `R` commences a re-boot operation in which the PC sends the reboot commands to the Point 4. You will be told to hit the APL key on the front panel of the Point 4 at two points in the reboot procedure.

4.6 Observing Procedures

4.6.1 Focusing the Spectrograph

The spectrograph can be focused by taking a series of exposures of comparison lamps, displaying each, doing a row plot through an isolated line and determining the FWHM of the line from a hardcopy of the row plot. This is extremely tedious given the time required to read and display each frame. An alternative procedure is to do multiple exposures on the same frame, with the focus and tilt changed between each. One can then read and display the resulting frame and determine the best focus. This is perhaps not the best procedure since a given spectral line falls on different parts of the chip for different exposures, but it is certainly quicker than the alternative and, in practice, results in an accurate focus determination.

The focus will generally fall in the range between 4.0 and 6.0. Use a wavelength region of low line density, if possible, to avoid confusion. He I λ5876 is generally a good choice. Do not turn on the Neon lamp.

To do a coarse focus, vary the focus by 0.4 units between exposures, starting at a focus of 4.0 and going to 6.0 in six exposures. You can then do a second test near the region of best focus by varying the focus by 0.1 unit. Vary the grating tilt by 0.02 between exposures. It is wise to vary it by 0.04 between the first and second integrations so that you know which exposure corresponds to which line on the final display.

The focus procedure can be carried out manually or under control of RCCS.

Manual Focus Procedure

1. Put an isolated line near the center of the chip. Note the grating *angle*. Say for example that it is near 8.00.

2. Set the focus to 4.0 using `FOCUS`.

3. Turn on the He-AR lamp.

4. Start a one-minute *Dark* exposure with `0 TEST`.

5. As soon as the integration begins, hit `Ctrl-S` to exit countdown mode and type `PAUSE`. The integration will stop.

6. Do the first of a series of integrations using `n LEX`. `LEX` will open the shutter for n seconds and then close it without reading the chip.

7. Move the tilt and focus by typing `ANGLE 7.96;FOCUS 4.4` into RCCS, when the motors are finished moving, type `n LEX` again.

8. Set the tilt and focus with `ANGLE 7.94;FOCUS 4.8`, repeat `n LEX`.

9. Repeat the above step for Focus = 5.2, 5.6, and 6.0 (Tilt = 7.92, 7.90, and 7.88, respectively).

10. When the last exposure is done, type `STOP`. The chip will be read out.

11. Display the frame with `0 TV`.

12. For improved accuracy, add several rows with `RSUM` and plot the result with `RPLOT`. For example, `150 250 0 RSUM RPLOT` will sum rows 150 through 250 of picture 0 and plot the result. Use the joystick to expand the plot about the columns of interest. The additional gap added between the first two exposures will orient you.

13. For critical focus, repeat the test with smaller focus steps near the position of best focus.

14. When the best focus position has been determined, set it with `FOCUS`.

Automated Focus Procedure

The rather repetitive procedure discribed above is well-suited for computer control. An automated focus procedure can be invoked with the RCCS command `AUTOFOCUS`. The user is prompted for the central wavelength, the length of the exposures, initial focus value, the focus and and tilt differentials, and a test frame number. The routine will then start a dark integration, storing the result in the specified test frame. At this point the only user intervention required is to stop the integration with a `Ctrl-S` once countdown mode is entered, and plot the result when the routine has finished. Six sub-integrations will be performed with tilt and focus changed between each. Default values can be adopted for all parameters.

4.6.2 When to Use a Blocking Filter

Other than the echellette, all gratings are blazed such that they are used in first order. Therefore, at wavelengths longward of about 6400 Å, second order contamination by light longward of 3200 Å begins. The extent of the contamination depends on the grating, the intrinsic color of the object, and the UV sensitivity of the CCD.

Normally, a UV-36, an L-42 and an LP-495 filter are in place in the spectrograph filter wheels. These extinguish light shortward of about 3600, 4200, and 4950 Å, respectively, thus making them effective filters for blocking second-order light while work in first order. Use these filters in the following approximate ranges: **UV-36** – 3600 - 7200 Å, **L-42** – 4200 - 8400 Å, **LP-495** – 5000 Å – 1 μ.

4.6.3 Wavelength Calibration, Bias, Dark, and Flat-field Frames

All lamps should be taken through the Open Hex pupil mask in the Top Box Hartmann Wheel.

Wavelength Calibration

Use the He-Ar and Ne lamp ensemble. The Hg-Cd lamp is filtered such that it has little output longward of 4000 Å. If you need a low line density lamp, the filter can be removed by the Instrument Specialist.

Typical integration times are between 10 and 30 seconds.

Etalon Exposures

The 0.05 mm gap etalon is suitable for use with the higher-resolution gratings. Their near-uniform line density makes etalons well suited for investigating spatial variations of the focus. Typical well-exposed frames require 10 to 30 second integrations with no filters in the Top Box neutral density filter wheel.

Bias Exposures

The CCD does have structure in its bias. Those demanding the ultimate in S/N would be well advised to accumulate multiple bias frames. Unfortunately, no facility exists for storing only the median of a large number of bias frames. However, a word does exist which allows the collection of the sum of a large number of bias (or other) frames.

`XCRUSH` allows multiple bias frames to be taken into a test picture area on disk and then summed into a permanent picture. Its use relies on the shutter state and the exposure time being set by the words `SHUTTER` and `DWELL`. Do not take zero-second exposures as the software will sooner or later make you regret it by screwing up the image transfers. `XCRUSH` and `WONT-WORK` (see below) are not loaded during boot-up and must be manually loaded by typing `476 LOAD`.

To carry out, for example, 5 bias frames and store the sum in frame 37, issue the following commands:

`DWELL`

Enter the integration time, say, 1 second.

`SHUTTER`

You want 'Dark' frames.

`476 LOAD`

`37 -1 5 XCRUSH` (where the -1 is the number of a test frame)

The computer will keep you advised of its progress.

Dark Frames

Long dark frames can be taken by simply specifying that the shutter should not be opened after issuing a `POBS`, `OBS` or `GO`. Ensure that the chamber lights are off during such frames since we cannot guarantee the absence of all light leaks.

To take a series of multiple darks, use the word `WONT-WORK`. This word repeats the current observation mode for a given number of times. Therefore, set the integration time and shutter as for bias frames, only setting the integration time to some large value (~ one hour). Load block 476 using `476 LOAD` and type `n WONT-WORK`, where n is the desired number of exposures. `WONT-WORK` must be the last command executed or else it won't work. That is, interrupting the countdown mode with a `ctrl-S` will cause some problems. Therefore, be sure that all status information is updated before issuing `WONT-WORK`.

Flatfield frames

Flats can be taken in a number of ways: chamber (i.e. 'dome') flats, sky flats, and lamp flats.

Experience has shown that the simplest of these to take, the lamp flats, remove high-frequency sensitivity variations with an accuracy better than one percent. Furthermore, fringing variations in the red can be taken out using lamp flats obtained at the same telescope position as the observation of the object, a procedure which is clearly impractical for chamber or sky flats. Lamp flats should be carried out using the 'Bright' continuum lamp. Exposure times are typically a few seconds with an ND 1.0 filter in the Top Box Filter Wheel.

Unfortunately, the comparison lamp feed does not illuminate the focal plane exactly the same way that skylight does. Specifically, it does not reproduce the complex vignetting pattern present at the periphery of the MMT field. Experiments show that over the central few arcminutes of the field, the disagreement is of order a few percent. Therefore, for accurate long-slit spectroscopy, it is recommended that users obtain exposures of twilight sky to determine the 'slit function'. Note that there is no reason to believe that the slit function is independent of grating or grating angle.

A facility exists to illuminate the inside of the chamber with quartz-halogen bulbs mounted at the top of the telescope structure. If you need such 'chamber flats', turn on the switch labelled 'DOME' on the observer's paddle. Ensure that the comparison mirror is out, and the Top Box shutter and mirror covers are open.

4.7 Cross-dispersed Mode

In cross-dispersed mode the 80 gpm echellette grating is used in conjunction with the cross-dispersion prism to give wavelength coverage from about 4500 Å to 1 μ with no gaps. The resolution with a one arcsec wide slit is a near-constant 250 km/s.

The maximum slit length which can be used in this mode is 20 arcsec. The entire chip must be used to record the data. That is, if the `SETUP` parameters exclude any columns of the CCD, lost wavelength coverage will result. Otherwise operation of the spectrograph and CCD are identical to non-cross-dispersed mode.

4.7.1 The Cross-Dispersed Format

A frame taken in this mode is reproduced below. The data are recorded in orders 4 through 8. Order four is the long wavelength order at the bottom of the frame; order 8 is at the top and contains He I λ4471. The slit length used was 20 arcsec.

4.7.2 Configuring Cross-Dispersed Mode

1. Have the camera box moved to cross-dispersed position. *This must be done by a member of the MMTO staff unless you have been specifically trained in this operation by the Instrument Specialist or Scientist.* The cross-dispersion micrometer mounted on the North side of the spectrograph should be set to 440. This will give full coverage in 4th order and will extend down to 4500 Å in 8th order. To sacrifice 4th order for extended blue coverage, set the micrometer to 520. This will extend the coverage shortward to about 4300 Å.

2. Insert the cross-dispersing prism. See Appendix E for details.

3. Insert the echellette with RCCS: `GRATING ECHELLETTE`.

4. Insert one of the short slit aperture plates using the RCCS `APERTURE` command.

5. For most cases, the format can be centered by issuing the RCCS command `ANGLE 5.36`. If you have a special need to center a particular wavelength, set the tilt with the RCCS commands `ORDER` and `WAVELENGTH`. Always set the order first, then set the wavelength. The

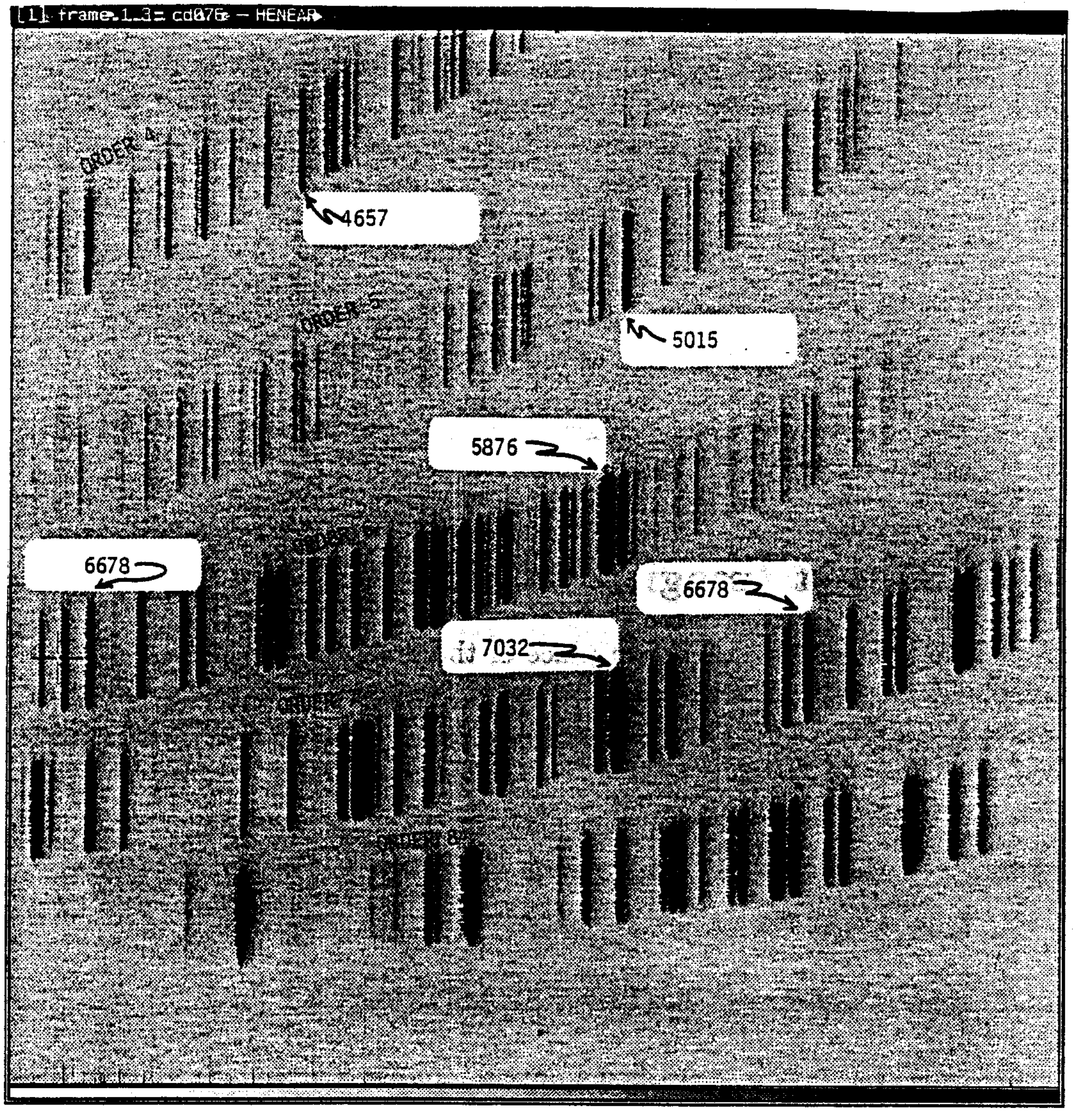


Figure 4.1: Red Channel cross-dispersed mode.

tilt angle should be near 5.36. If after setting the central wavelength the angle is *substantially* different from this, drive the tilt to 5.36 with the RCCS command `ANGLE 5.36`. Take a comparison frame and display it. The wavelength zero-point can then be reset by identifying a line in some order, say for example 6678 in order 5. Find its position in the echellette dispersion direction using `JS` and then issue the following RCCS commands:

`BMODE 800`

`ORDER 5`

`ZERO/U 6678` n (where n is the pixel position of the line)

The grating can know be driven to the proper wavelength with the `WAVE` command.

4.8 Direct Imaging Mode

A flat mirror can be inserted in place of the grating, making the spectrograph a focal-reducer suitable for use as an imager. In this mode the image scale at the detector is 0.33 arcsec/15 μ pixel. We have an aperture plate with a 2 arcmin diameter circular hole which can be used in this mode.

4.8.1 Configuring Imaging Mode

1. Ensure that the spectrograph is in non-cross-dispersed mode.
2. Insert the flat with the RCCS command `GRATING FLAT`.
3. Move the appropriate filters into the beam via the `LFW` and/or `UFW` commands.
4. Insert the direct imaging aperture plate with the RCCS command `APERTURE DIRECT`, or, if you are not using a plate use the RCCS command `APERTURE MAGNETIC`.
5. Set the angle of the flat with the RCCS command `ANGLE 3.52`.

If the image is not well centered on the chip, its position can be moved using the `ANGLE` command. The image moves about 165 pixels per 0.1 unit.

4.8.2 Guiding in Direct Imaging Mode

Guiding is difficult in this mode given the small size of the MMT field. Three options are listed below in increasing levels of difficulty:

1. Free-run the telescope. For short integrations one can stack the telescope, insert the direct imaging aperture plate (or remove the aperture plate) and start an integration. The tracking of the telescope is adequately good that this should work for integrations of ten minutes or less, given that the telescope is in reasonably good tune.

2. Guide with the 85 mm lens. Stack near the center of the field using a spectrograph aperture plate, insert the direct imaging plate and locate a star on the periphery of the field and guide on it with the 85 mm lens. This is difficult because the scale is so large. Common-mode autoguiding, in which error signals are sent to all secondaries in order to maintain the position of the centroid of the stacked image of an offset star, can be used in this mode. Please alert the Instrument Scientist of your intention to use common-mode autoguiding in advance of your run.

3. Guide with the I-CCD using the AWPs. The AWPs (see Chapter 7) allow one to steer the 200 mm field around the full MMT field to find a guide star. In this mode, autoguiding signals can be applied to the individual secondaries using the offset autoguiding TCS software. Interested users should have a list of accurate coordinates for guide stars before coming to the telescope and should contact the Instrument Scientist *well in advance of their observing run.*

Chapter 5

System Throughput

5.1 Blue Channel

5.1.1 Measured Throughput

The throughput of the Blue Channel using the 300 gpm grating was carefully measured in February of 1985. The measurement and analysis procedures are described below.

Telescope Configuration

The test was carried out on the night of February 12/13, 1985 (U.T.). The MMT primaries were last washed on January 29, 1985. No windy conditions had been encountered since the washing so it is assumed that the primaries were fairly clean at the time of the test. It had been roughly seven months since four of the primaries and all of the small optics were re-aluminized.

Spectrograph Configuration

The test was performed using the 300 g/mm grating in first order centered at 5500 Å. The usable wavelength region extended from roughly 3150 Å to about 7700 Å. No filters were inserted in the beam. Note that beyond about 6400 Å, the data are contaminated by second-order light – no attempt has been made to calibrate the extent of the second-order contamination as we were particularly interested in the UV and blue regions of the spectrum.

Observing Procedure

The standard star used for the measurement was G 99-37 (= EG 248), which is classified in the KPNO IIDS Standard Star Manual as a DGp(CH) star. The star has a monochromatic magnitude of 14.51 at 5556 Å.

The standard star was observed through the 5 arcsec circular apertures using the image from one MMT primary at a time. This procedure obviated the need for neutral density filters behind the slit. Note that this star (and most of the Stone and Oke standards) is too bright to observe the stacked image of all six primaries simultaneously. Each image was observed for 60 seconds in each aperture except A and B which were observed for 120 seconds in each aperture (impatience prevailed). The data for the latter two primaries were corrected for this imbalance in integration time.

The object was observed at an average airmass of X=1.20. Throughout the observation, the seeing was always better than 1.5 arcsec and the transparency was excellent.

Wavelength calibration was made with an exposure of the He-Ar and Neon lamps observed through the 1×3 arcsec slits. The reality of the feature identified as He I λ3187 is in question. As a result, the wavelength calibration shortward of about 3500 Å is uncertain by perhaps up to 5 Å. The standard fluxes are defined only longward of 3320 Å.

No flatfield correction was carried out. This should not be a source of error as the pixel-to-pixel variations observed on the same night with a different grating were about 5% (1 sigma).

The data were binned into 1 Å pixels from 3150 Å to 7700 Å and corrected for 1.2 airmasses of extinction using an extinction model scaled to the altitude of the MMT.

Analysis Procedure

The data were binned into bandpasses of 80 Å for $\lambda > 5880$ Å and 40 Å shortward of 5880 Å after correction for atmospheric extinction and division by the collecting area of the MMT. These bandpasses were centered at the positions of the Oke bandpasses. The result approximates the number of detected photons per Oke bandpass per second per cm^2 were we able to remove the atmosphere. The Oke AB magnitudes were then converted to incident photons per second per cm^2 per bandpass at the top of the atmosphere. The ratio of these two quantities was calculated for each bandpass to give the wavelength-dependent quantum efficiency of the system. Note that no attempt was made to account for the grating efficiency in this analysis.

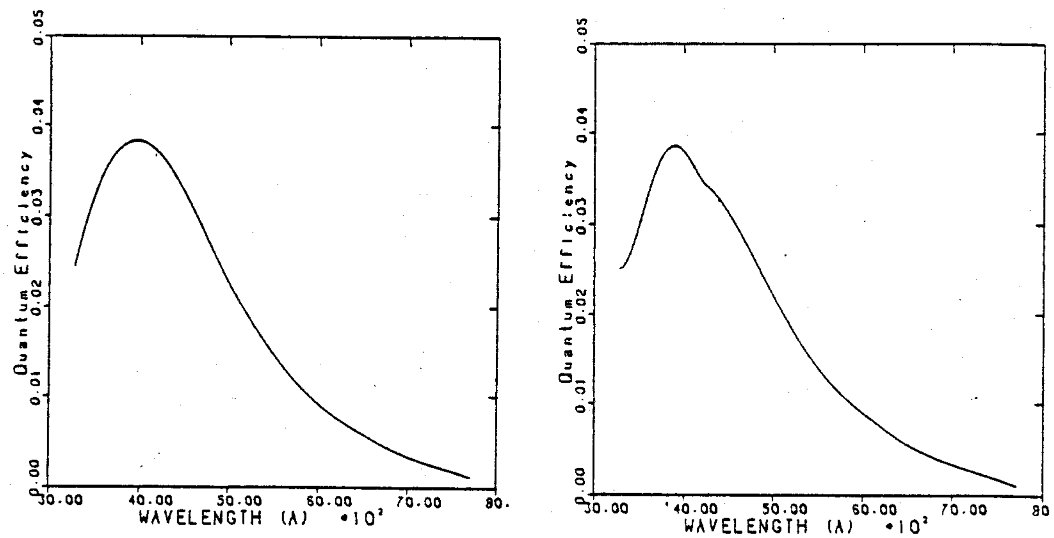


Figure 5.1: Quantum efficiency as a function of wavelength for each aperture.

The resulting quantum efficiency points were fitted with 'spliced' polynomials to give a smooth curve for each aperture independently. In this procedure the data were divided into three regions covering roughly equal wavelength regions and polynomials of third or fourth order were fitted to the data in each region with the additional constraints that the functions and their first derivatives be continuous across the boundaries between regions. The uncertainty of the points about these curves expressed as $\Delta qe(\lambda)/qe(\lambda)$ was typically 0.05 to 0.10.

Results

The results are presented for the left and right apertures, respectively, in Figure 5.1. The variations seen between the two curves are due to variations in the joining conditions and positions of boundaries in the fitting procedure and should not be construed as real variations in the responses of the two apertures.

Note that the general agreement between the two apertures is quite good yielding a peak efficiency for the MMT - MMT Spectrograph combination with the 300 gpm grating and Big Blue II detector of ~3.8% at ~4000 Å.

Measurements of the reflectivity of the MMT optics were obtained after the last washing of the primaries (January 29, 1985). The average reflectiv-

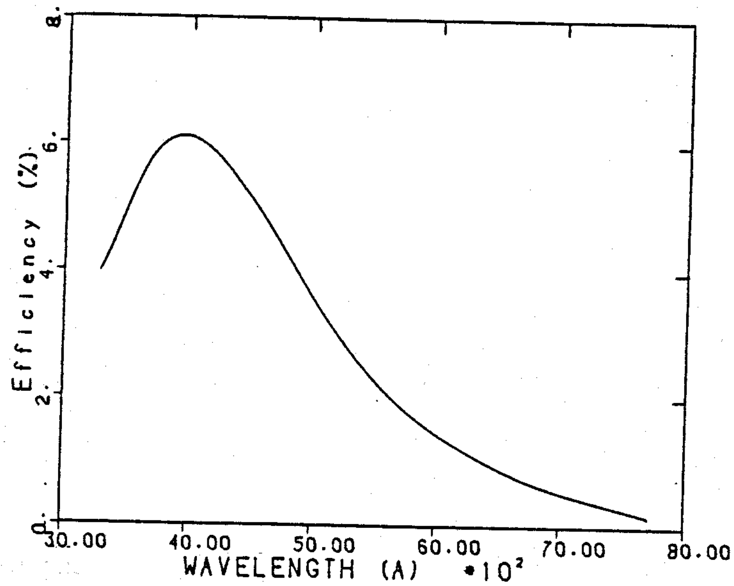


Figure 5.2: Quantum efficiency of the Blue Channel with 300 gpm grating

ity of the optical surfaces was 89 (+0.5/-1.0) %. Assuming no other losses in the MMT optics, this implies a throughput of the MMT of 63%.

Figure 5.2 shows the average of the throughput of the two spectrograph apertures corrected for the absorption losses of the MMT optics. The resultant efficiency of the MMT Spectrograph-Big Blue II combination peaks at just over 6% at about 4000 Å.

5.1.2 Relative Throughput of the 600 and 832 gpm Gratings

The figure below gives the relative efficiency of the 600 gpm grating used in second order with the 832 gpm grating used in first and second order. These configurations have the following properties:

Grating	*Order*	*Resolution/ Coverage*	*Filters Required*
600	2	1.4/1250	CuSO4, L42, and/or UV36
832	2	1.0/900	CuSO4, L42, and/or UV36
832	1	2.0/1800	L42 to block second order blue

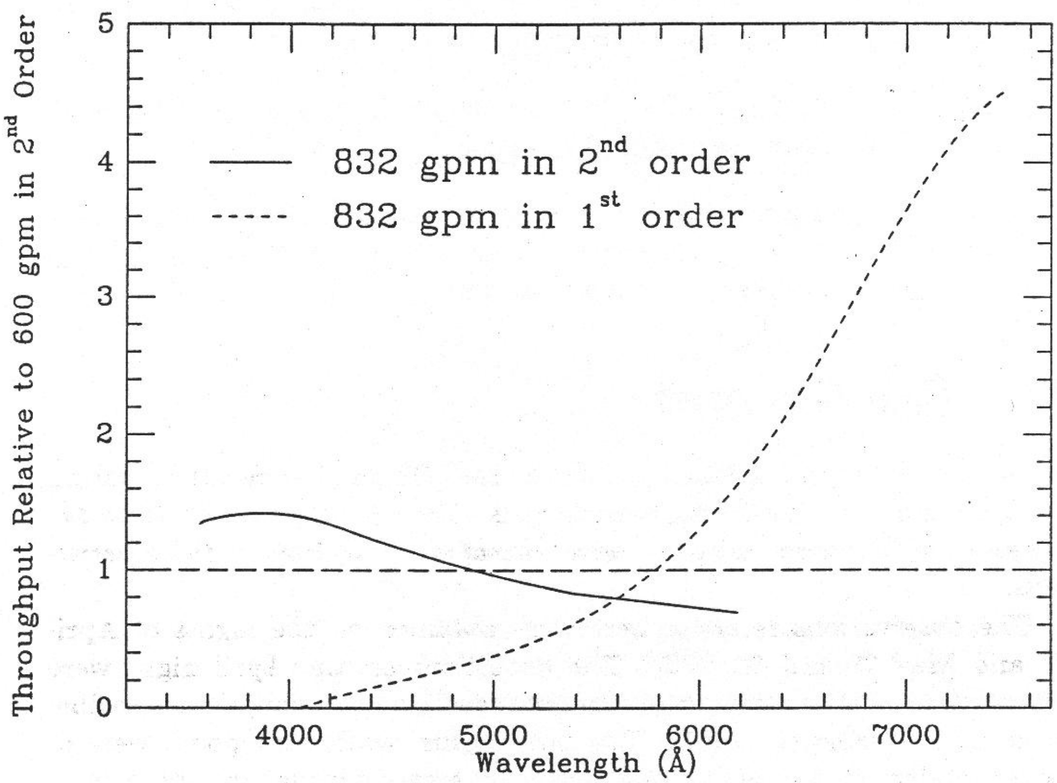


Figure 5.3: Relative throughput of the 600 and 832 gratings.

Note that the figure presents the relative efficiency as counts/Å/s. General rules to choose gratings by include:

1. Shortward of about 4950 Å use the 832 gpm grating. Longward, use the 600 gpm if you can abide slightly lower resolution.

2. If you are working in the blue, use the 800 gpm grating centered at 4100 Å for coverage from 3200 to 5000 Å.

3. The 832 gpm grating used in first order is a good choice for moderate resolution at red wavelengths. Keep in mind that the image tube response is declining at long wavelengths.

5.2 Red Channel

Measurements of the throughput of the Red Channel were taken during the April and May (1988) engineering runs. *The refractive optics (with the exception of the dewar window) were uncoated at the time of the observations.*

The observations reported here were obtained on the nights of April 26, and May 25 and 26 (UT). The conditions on the April night were near perfect — the seeing was sub-arcsecond and no clouds were visible at any time during the night. The May nights, while very good, were of poorer quality — the seeing was about 1.5 arcsec throughout the nights, and clouds were always visible. At times, however, less than 10% of the sky was covered by clouds. The throughput measurements were taken during such clear periods, but we cannot be sure that they were unaffected by clouds. The effect of clouds is to cause us to underestimate the throughput of the spectrograph.

Observations of standard stars from Oke's list were made through dual 5 arcsec diameter circular apertures when using the 270 and 1200 gpm grating and through a 5 arsec by 20 arcsec slit in the case of the echellette data. In some cases starlight was visible outside of the aperture, though we expect that this would cause us to underestimate the throughput by a negligible amount.

The data were de-biased and extracted from the the two-dimensional frames. No flat-fielding of the images was performed. The cross-dispersed (echellette) data were sky-subtracted during the extraction of the curved orders; the sky was subtracted from the single-order data after the extraction to one-dimensional format. IRAF was used for these stages of the data reduction. The one-dimensional spectra were divided by the exposure time, wavelength-calibrated, and corrected for extinction. The latter correction assumed a mean extinction curve and did not attempt to remove discrete atmospheric absorption features (e.g. the A band).

Finally, the data were divided by the collecting area of the MMT and multiplied by the CCD gain, the number of photons per digital unit. The latter was determined to be 2.6 photons per data number (and the readout noise was determined to be 7 electrons) by Bob Leach in his lab and confirmed by us on the mountain during the May run. The spectra were then measured by forming averages in the Oke bandpasses, yielding the number of detected photons/second/cm^2/Å. The ratio of this number to the number of photons expected from a star of known AB magnitude gives the throughput of the telescope-spectrograph-detector combination. To correct for the telescope reflectivity, we have divided the results by 0.89^4, the approximate throughput of the MMT.

The resulting measurements are presented for representative bandpasses for the 270 and 1200 gpm gratings in Figures 5.4 and 5.5. Note that the peak efficiency for each, at $\sim$ 17%, is *very high.*

In the case of the echellette, smooth functions were fitted to the measured efficiency points for each order from order 4 through 8. These are shown along with the sum of the orders in Figure 5.6. The discontinuities in the sum are due to incomplete coverage of the orders due to the small size of the detector. This incomplete coverage can be seen in Figure 5.7 where we present the raw data. The peak throughput of the echellette is just under 10%, considerably below that of the other gratings. In large measure, this is due to the high incidence angle air-glass interfaces of the cross-dispersing prism. Note that all of the measurements reported above were obtained before the application of anti-reflection coatings on the optics. The throughput improvement as a result of their application should be most dramatic in cross-dispersed mode.

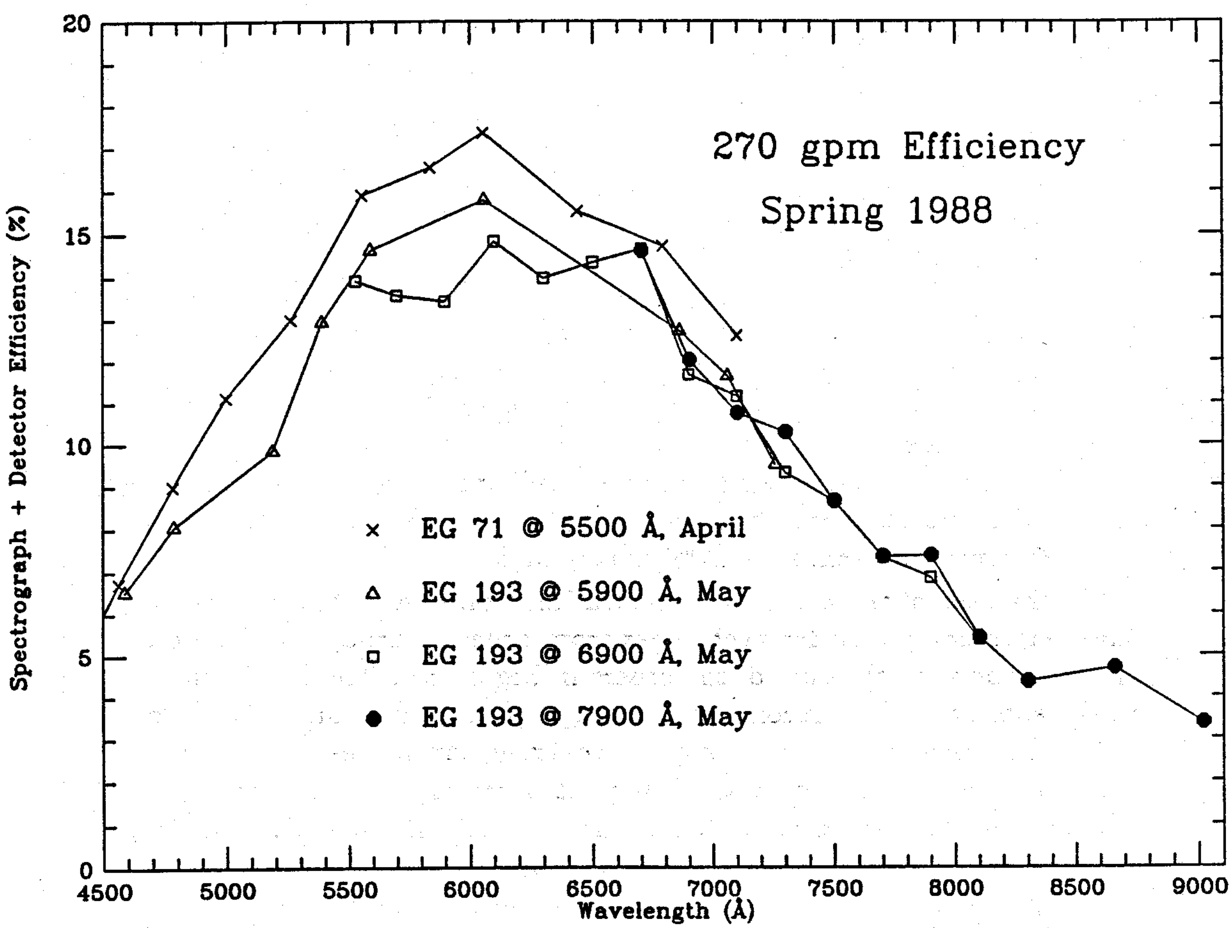


Figure 5.4: Red Channel throughput with 270 gpm grating.

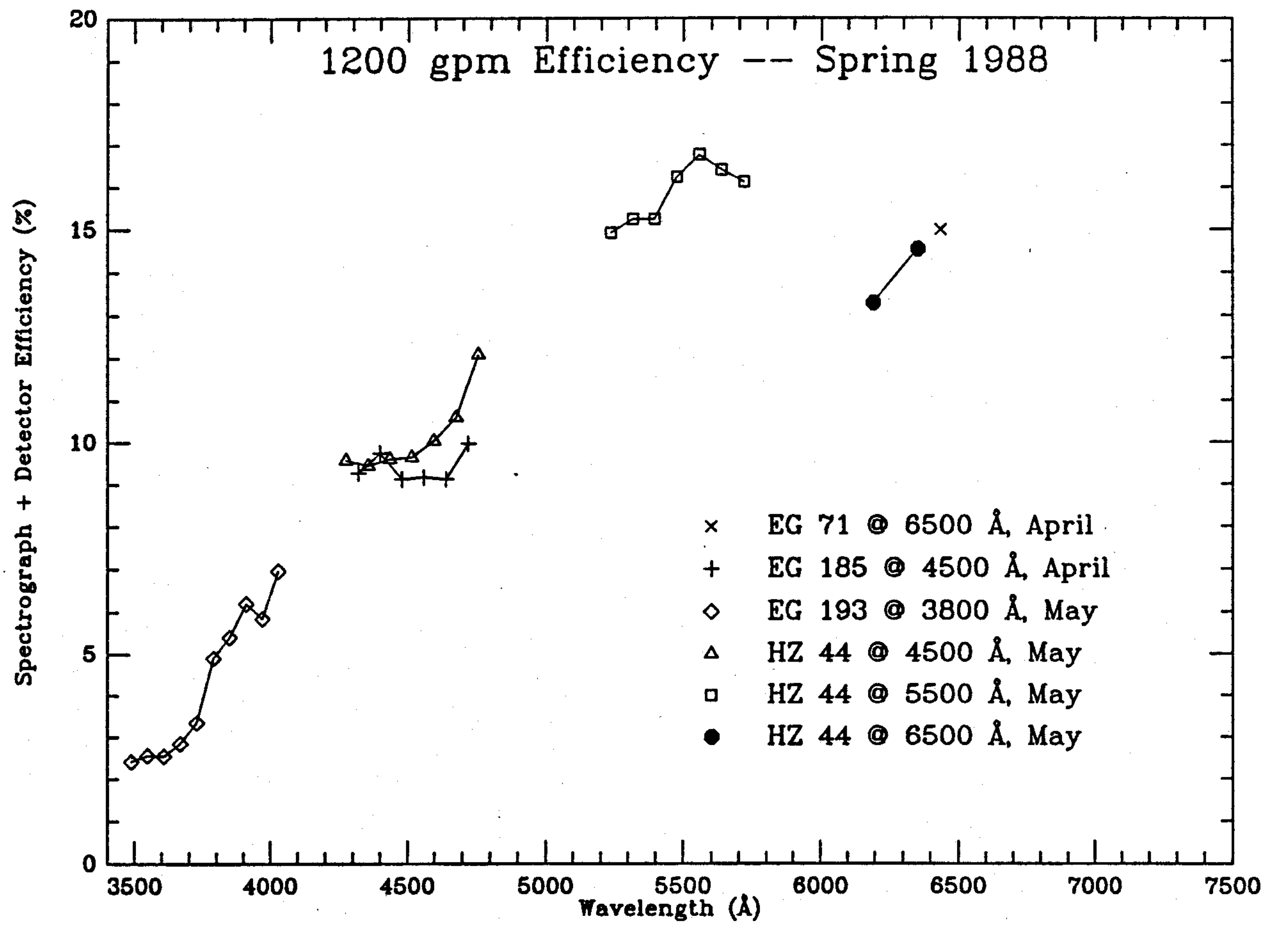


Figure 5.5: Red Channel throughput with 1200 gpm grating.

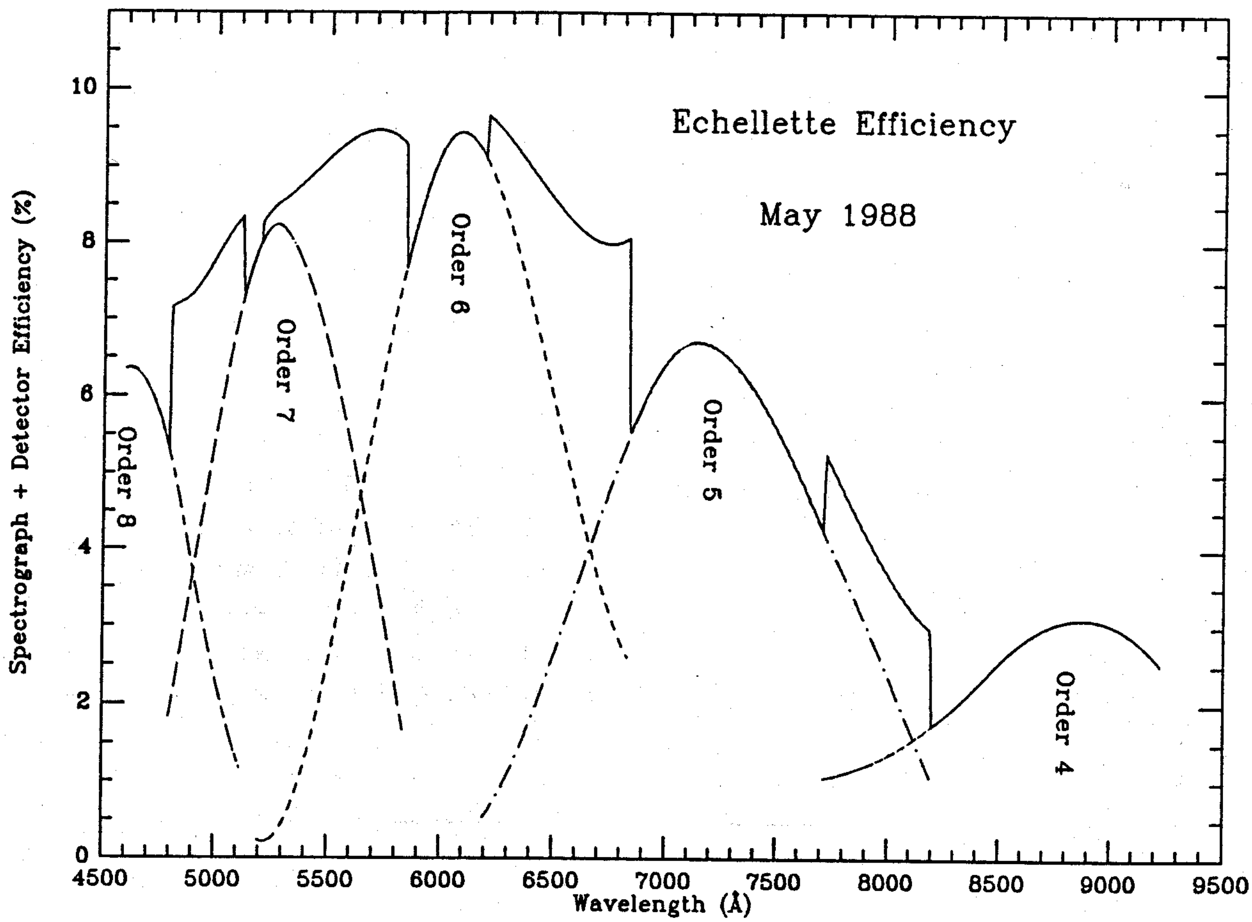


Figure 5.6: Red Channel throughput with echellette grating.

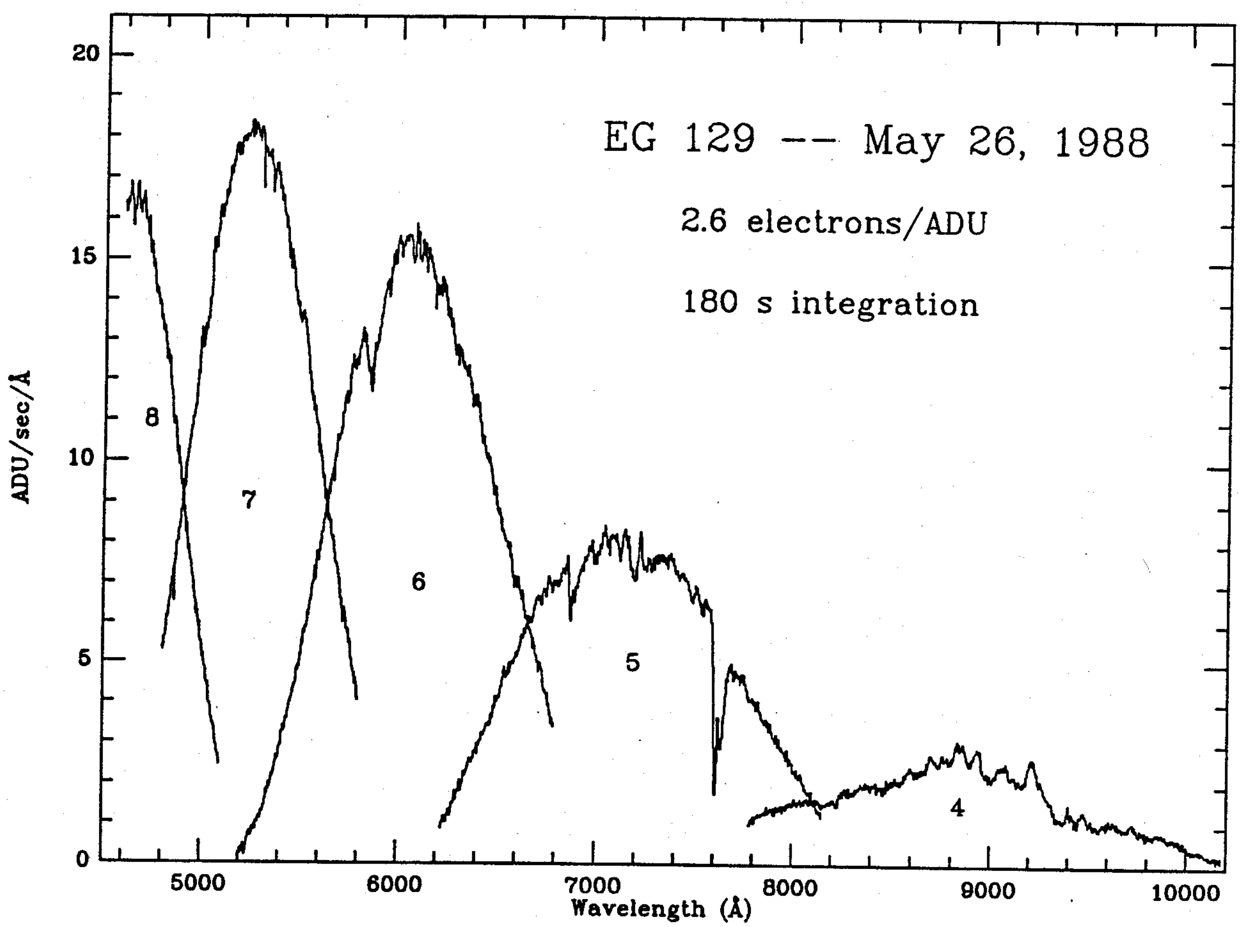


Figure 5.7: Raw data observed with echellette. Note truncated orders.

Chapter 6

Performance and Operation of the Image Stacker

6.1 Description and Performance

The Image Stacker consists of a set of very small lenses mounted on a module which occupies one of the aperture wheel positions and can be selected just as any aperture can be. Its function is to redirect the beams from each of the six primary mirrors so that, in effect, the spectrograph appears to operate with an f/31.6 collimator rather than the f/9.0 collimator characteristic of the slit mode. This means that the collimator-to-camera focal ratio is very large with a consequent very large reduction between the entrance aperture size and its image size at the detector. Thus, its value lies in producing high resolution spectra while at the same time utilizing a relatively large set of entrance apertures (specifically, 2.5 arcsec circles) thus letting in a large fraction of the stellar image, even in relatively poor seeing.

There is some loss of light associated with the device (about 20%) but this is more than compensated for by the increased throughput at the slit compared to the 1×3 arcsec slits which produce about 5–10% poorer resolution than the stacker. Typically, a gain in throughput of about 1.5 results from the use of the stacker compared to the 1×3 arcsec slits during typical seeing conditions. However, since the stacker produces two sets of six spectra each, a sizable readout noise penalty is paid when using the stacker with the Red Channel.

It is important to realize that the sky background increases as the area of the *individual* 2.5 arcsec stacker apertures compared to the area of whichever normal entrance aperture is selected, since only those sky photons from mirror A (for example) which pass through aperture A are imaged on the detector. Sky photons from mirror A passing through the B, C, D, E, and F circular apertures are rejected at about the 1% level or less.

In summary, if you want the best available resolution and your object is brighter than about 18.5 (so that sky background is not a dominant noise source) then use of the stacker is recommended. The order in which the apertures appear in order of decreasing elevation as projected onto the sky is: **B C A F D E** (Before Casual Affairs, Find a Desirable Environment). Note that the image rotator cannot be used in the stacker mode and must be set to its nominal 0.0 degree position (i.e. apertures lined up along a line of constant azimuth).

6.2 Using of the Image Stacker

1. Select the stacker position of the aperture wheel with the BCCS or RCCS command `AP IM`.

   If you are using the Red Channel, you will need to change the focus of the spectrograph by a considearble amount. Contact the Instrument Scientist. If you are using the Blue Channel, proceed as follows:

2. Make sure the camera shutter is closed and the telescope is in the stow position (zenith).

3. Loosen the 2 thumb screws on each side of the collimator module: 4 in all.

4. Turn the small fold-out crank handle mounted on the knob at the top rear of the collimator module until the *coarse* collimator dial indicator reads 2.238. Back off the crank about a half turn to relieve the tension on the thumb bolts. Tighten the 4 thumb screws. Do not overtighten.

5. On the side of the spectrograph facing closed end of the chamber (North) is another dial indicator for adjusting the height of the total internal reflecting prism (TIRP). Near the dial indicator is a rectangular block with two knobs protruding from its north end. The top brass knurled knob locks the TIRP into place; the bottom black knob is the end of a telescoping lever. Pull the lever out until it hits its stop (about 5 inches). While holding the lever in one hand, loosen the brass knob with the other and slowly lower the lever until the dial

indicator reads 0.760. Still holding the lever, tighten the brass knob. Do not overtighten.

6. If you're feeling particularly compulsive, raise the fine focus by three units.

7. To return to slit mode reset the fine collimator focus 3 units lower, set the coarse collimator indicator to 0.640 and set the TIRP dial indicator to 0.465. Select the appropriate normal slit apertures.

Chapter 7

The Top Box

The Top Box contains the various subsystems necessary for autoguiding the MMT as well as the comparison lamp illumination system. We describe here only those systems which have an impact upon users of the spectrograph. Details of the other aspects of the Top Box can be obtained from the MMTO.

7.1 Television Acquisition and Guiding

Two television cameras are available for using in object acquisition and guiding. These can be selected from the Control Room. Both are intensified; one (I-CCD) uses a Fairchild CCD camera as detector, the other (I-Vid) uses a vidicon. The control of these cameras is the responsibility of the Telescope Operator.

Each camera is equipped with motorized stages to select either an 85 mm focal length reimaging lens or a 200 mm lens. All lenses are Canon 35 mm format. The former reimage effectively the full field (about 4 arcmin) of the MMT onto the detector, the latter, roughly 2 arcmin. Contrary to the lore which has developed around these lenses, the depth of vision, i.e. the magnitude of the faintest object visible, does not change appreciably when lenses are changed.

The depth of vision of the two cameras are identical when each camera is performing well. Under good seeing and dark sky conditions, stellar objects are visible to roughly $V \simeq 21$.

Either camera can be used as input to the TCS computer and TCS Grinnell image display system. The Grinnell can be used as a leaky memory to increase the effective integration of the cameras.

The I-CCD is mounted behind the Top Box Pupil Wheel and AWP (achromatic wedge prism) assembly. While a clear position exists in the pupil wheel, the AWPs are always in place. They can be used to steer the TV field around the full field of the telescope even when the 200 mm lens is in place. The I-CCD camera is needed for use when autoguiding on a stacked image.

7.2 The Observer's Paddle

The Observer's Paddle is used for the manual control of the Top Box functions and several other instrument-related tasks. These include:

1. Comparison and calibration lamps.
2. Comparison mirror.
3. Top Box filter wheel.
4. Hartmann mask filter wheel.
5. Overillumination alarm.

In order to control the Top Box functions manually, the SCCS/Paddle mode switch must be set to paddle. If you want to change modes and SCCS is running, switch this mode switch and issue the BCCS or RCCS command `TOPBOX ON`.

7.2.1 Lamps

The lamps are controlled by a set of nine toggle switches and a push-button located across the top of the paddle. The toggle switches enable the individual lamps. Setting a toggle switch up enables that lamp. The push-button to the right of the row of toggle switches turns all enabled lamps on and off by repeated depressions of the button. Burning lamps are witnessed by LEDs adjacent to the toggle switches. Note that these LEDs are triggered by current sensors and are therefore reliable indicators of whether the lamps are lit.

Enabled lamps are extinguished whenever either the Top Box filter wheel or Hartmann wheels are turning.

Some lamps (notably the bright continuum source and the "DOME" lamps) can be disabled remotely and, therefore, might not light when commanded by the paddle.

Lamps fed by fibers to the integrating sphere (all except He-Ar, Th-Ar, and Bright) can be on during integrations on celestial sources without contamination of the spectrum, so long as the comparison mirror stays out of the beam. This means that, for example, the Hg-Cd lamp can be warmed up during an integration. The He-Ar, Th-Ar, and Bright lamps are located in the top box and should not be on during integrations of program objects.

7.2.2 Comparison Mirror

The mirror is controlled by a two-position toggle switch on the right side of the paddle. LEDs indicate its position. The Telescope Operator may take control of the mirror with the Operator's Paddle (which has priority over the Observer's Paddle). If the mirror does not move when you switch it, ask one of the day crew to check if the Operator's Paddle is in the OBS position.

7.2.3 Filter Wheel and Hartmann Wheel

These are run by two sets of octal thumb-wheel switches, single-digit seven-segment led displays, and push-buttons, one set for each wheel. The individual positions of each wheel are encoded by numbers from 0 through 7. A table relating the numbers to the contents of each position is attached to the top of the paddle. The seven-segment LEDs give the current position of the wheels.

To change the position of a wheel, dial in the desired position on the octal thumb-wheel and depress the adjacent push-button. The busy light will come on while the wheel is moving. When the wheel is indexed, the busy light will go out and the new position will appear on the seven-segment LED. All lamps are extinguished while the wheel is moving.

7.2.4 Pupil Masks

The illumination scheme used in the Top Box was designed to mimic the beam of the MMT as closely as possible. That is, it was desired to have the beam from the integrating sphere simulate six f/32 beams enclosed in an f/9 envelope. Two accomplish this, pupil masks are available in the Hartmann wheel. The available masks are:

0. Dark

1. Left Hartmann

2. Right Hartmann
3. Open Hex
4. Left Hex Hartmann
5. Right Hex Hartmann
6. Hex + 2.0 ND filter
7. Clear

Observers should use masks 3 or 7 for normal operation. With most of the normal lamps it is not necessary to use the additional ND filtration provided by 6. Masks 1 and 2 are used for Hartmann focusing of the spectrograph in slit mode; masks 4 and 5 for image stacker mode.

7.3 The NEMA Box

The NEMA Box houses the comparison lamps and fiber feeds to the integrating sphere in the Top Box. With the exception of the He-Ar, Bright, and Th-Ar lamps, all lamps including the etalons are housed in the NEMA Box. The box is located on the north end of the east wall of the second level Instrument Laboratory. The box is normally kept locked. Observers should not modify the lamp feeds in the box without first receiving permission from the Instrument Specialist.

Lamps can be individually filtered as desired. The Instrument Specialist can help you with any custom illumination requirements.

Chapter 8

Using Etalons for Wavelength Calibration

The installation of the Top Box with its comparison lamp illumination scheme has provided us with the flexibility needed to experiment with alternative sources for wavelength and flatfield calibrations. Unfortunately, the wide field of the illumination has caused the projected surface brightness of the Thorium-Argon (Th-Ar) lamp to decrease by a factor of 2.5 from the only-adequate level in the old Top Box. In an attempt both to alleviate this problem and to provide a better wavelength-calibration source, we are experimenting with using the Edser-Butler bands produced when parallel plates (Etalon) are illuminated with collimated white light as wavelength calibration features. The purpose of this section is to report on some recent experiments which we believe demonstrate the promise of using etalons for wavelength calibration.

For the purpose of this discussion, we consider an etalon to be composed of two flat, partially transmitting mirrors which are parallel to each other. In the case considered here we use an etalon from one of the PEPSIOS triplets (generously loaned to us by Dr. N. Carleton). The etalon is composed of two plates separated by air. Each plate has a partially-transmitting coating on one surface and an anti-reflection coating on its other surface. The latter surface is slightly wedged with respect to the former to avoid forming additional cavities.

When the cavity formed by the two partially-transmitting surfaces is illuminated with a beam of coherent monochromatic light, it will transmit the beam when the optical path length between the surfaces is such that constructive interference occurs. Conversely, illumination with parallel white light produces an output spectrum of fringes with near-constant spacing (the so-called Edser-Butler bands). The condition for constructive interference for a transmitted wavefront is:

$$2nd \cos \theta = m\lambda$$

where:

n = the refractive index of the medium between the reflecting surfaces,

d = the spacing between the reflective surfaces,

θ = the angle between the normal to the mirrors and the direction of the incoming radiation,

m = the order of interference, and

λ = the wavelength of the light.

From this condition, the free spectral range or fringe separation follows as:

$$\Delta\lambda_{FSR} = \lambda^2/2nd$$

Finally, we define the finesse, F:

$$F = \Delta\lambda_{FSR}/\Delta\lambda_{BW}$$

where $\Delta\lambda_{BW}$ is the FWHM of the fringe.

The etalon and collimated light source are located in the NEMA box on the east wall of the second level instrument lab. This box contains the other comparison sources (with the exception of the Th-Ar, Bright, and He-Ar lamps) and the termination of the fiber optic feeds to the integrating sphere in the Top Box.

The filament of a quartz halogen lamp is imaged onto a 600 μ diameter pinhole. The light passing through the pinhole is then collimated by an f/4 2 inch lens. After passing through the etalon, the light is re-imaged onto the 600 μ end of the fiber with an f/2 2 inch lens.

The parallelism of the etalon plates is established by illuminating them from below with diffuse light from a mercury vapor discharge tube. The adjustable point supports of the etalon were adjusted until the resulting circular fringes remained constant independent of viewing angle. This procedure is difficult to describe but is simple and self-evident in practice. This procedure is carried out by the Instrument Specialist when the etalon is installed in the NEMA box.

One shortcoming of our etalons is that their coatings are adequate for wavelengths longward of about 4500 Å. Shortward of about 4000 Å, the etalons are probably useless due to poor finesse resulting from the degraded reflectivity of the PEPSIOS etalon surfaces.

Since the NEMA box is not temperature or pressure stabilized, two integrations are needed to perform a wavelength calibration. The aim of wavelength calibration, of course, is to determine polynomial coefficients relating wavelength to pixels by some appropriate means. Typically 5th to 7th order polynomials are used. Calibration by means of an etalon exposure requires that two additional parameters be determined: m, the order of an arbitrarily chosen fringe, and 2nd cos θ, twice the effective plate spacing. The determination of these parameters can be carried out simultaneously by a suitable least- squares technique.

We point out one of the obvious advantages of using the etalon fringes as wavelength references. The size of the largest unfit region is small regardless of the wavelength at which one is observing and fringes are available over virtually the entire sensitive length of the detector.

There are currently three etalons available for general use. All have the same coatings. Their properties are summarized in the table below:

Etalon Number	*Approximate Gap (mm)*	*Suggested Gratings*
1	.7	8th order echellette
2	.17	600 gpm, 832 gpm, echellette
3	.05	300 gpm, FOGS, Red Channel

If you are interested in using the etalons, please be advised that they are not thoroughly debugged yet. We are not absolutely certain of the maximum attainable accuracy of wavelength calibration with the etalons. Contact the Instrument Specialist or Scientist for details and indicate your desire to use the etalon on your Observing Run Preparation Form.

Appendix A

Comparison Source Maps

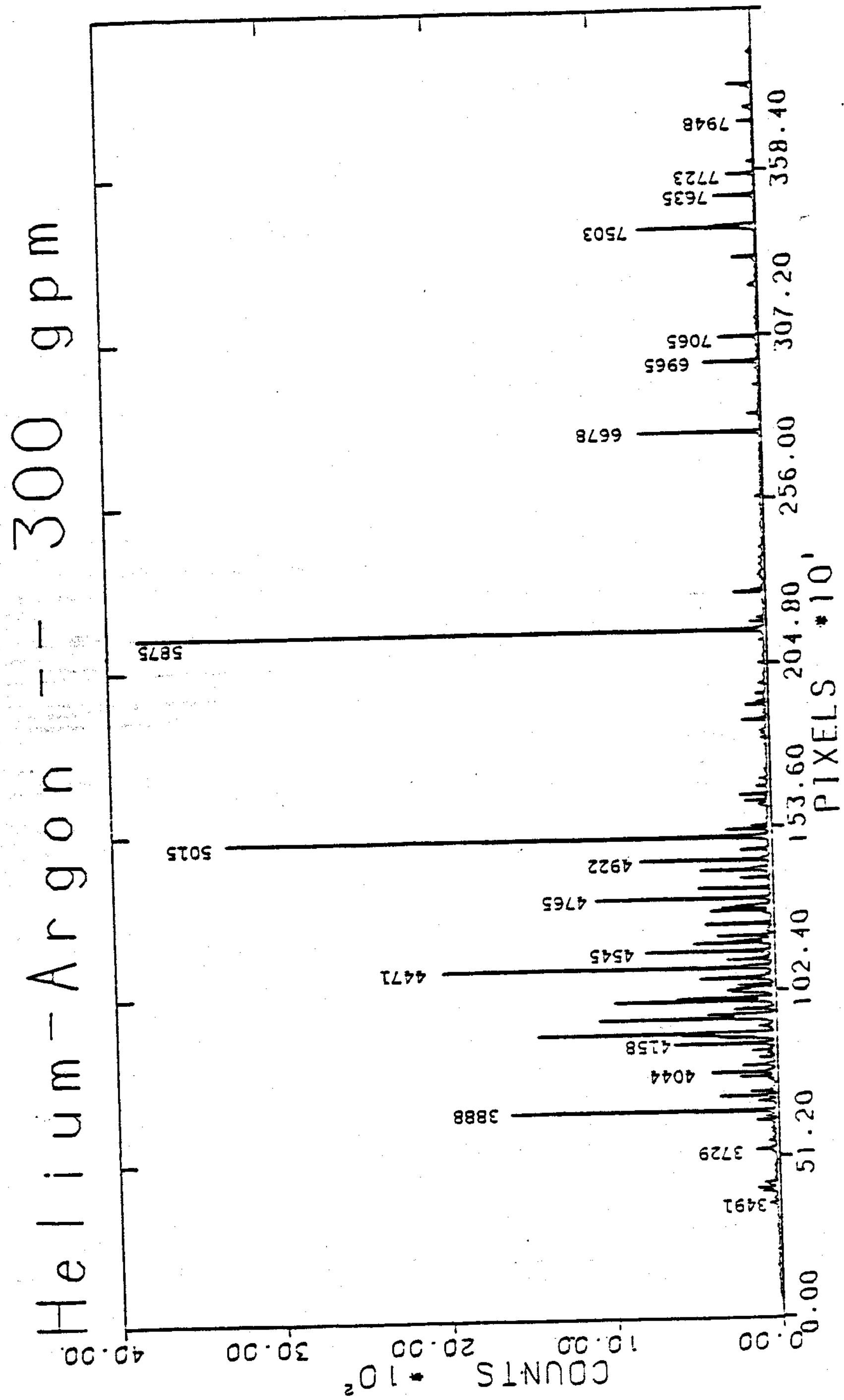
Several comparison source maps are reproduced on the following pages. These are intended to be used to assist in grating setup and not in data reduction. That is, in the production of these plots, no effort was made to identify all of the lines and/or exclude blends.

Only the Helium-Argon, Mercury-Cadmium, and Neon sources were used. Exquisite maps of the Thorium-Argon spectrum are filed in the documentation rack.

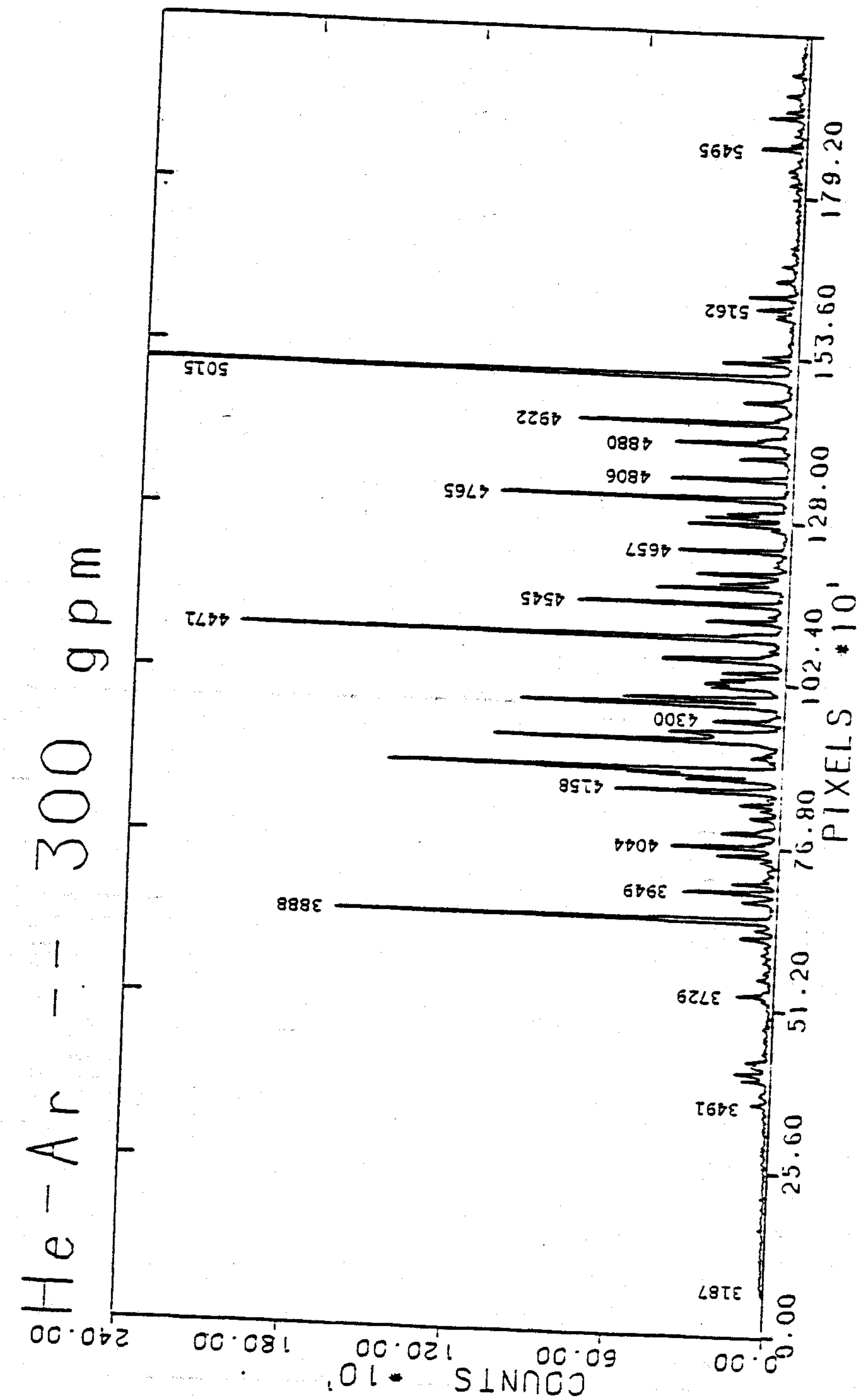
Brief descriptions of the various figures follow.

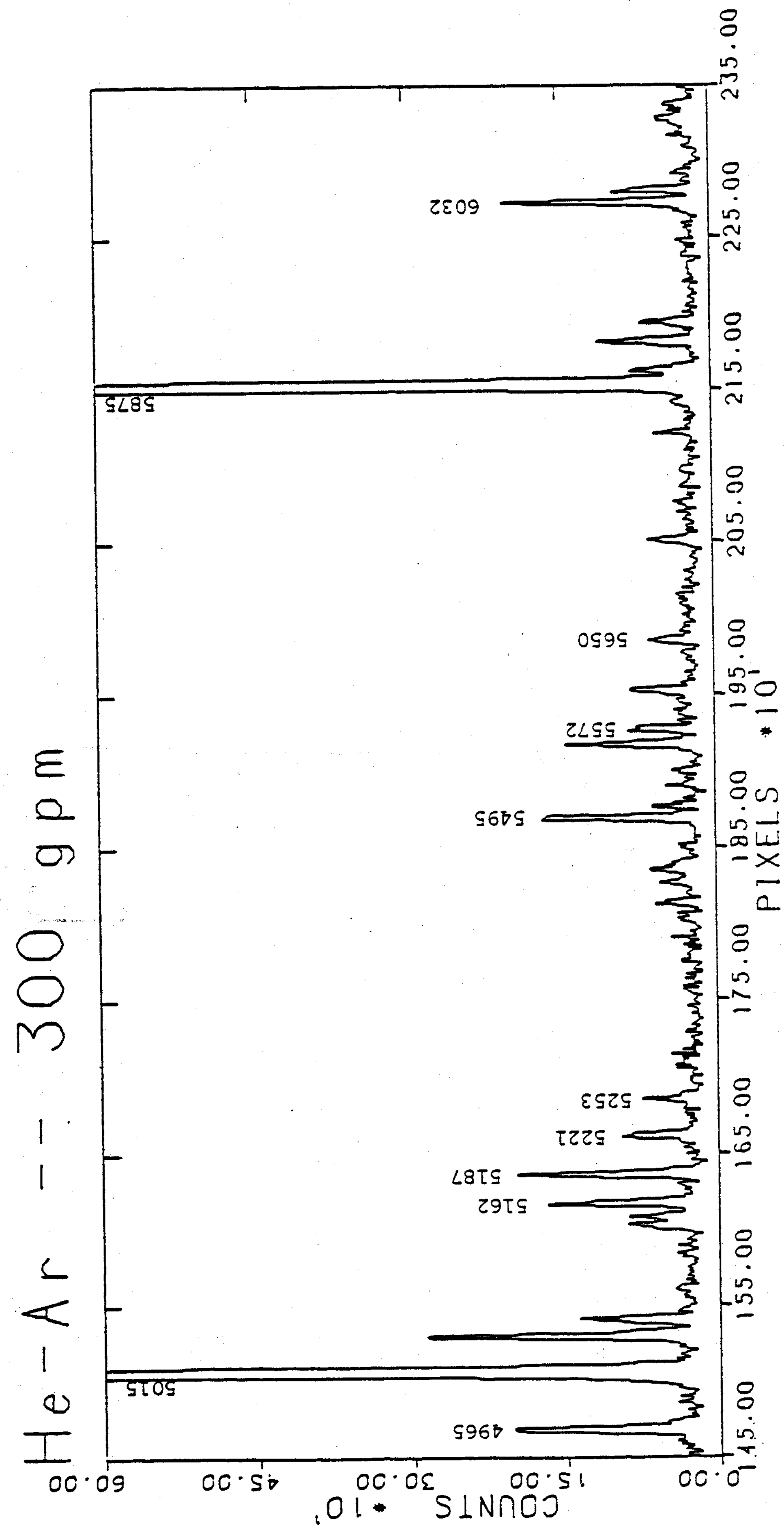
- Figure A.1. Spectrum of the He-Ar lamp obtained with the 300 gpm grating through the 1×3 arcsec apertures. No filter in either of the behind-the-slit wheels.
- Figure A.2. Blow-up of the first 2048 pixels of A.1.
- Figure A.3. Blow-up of the region between 5015 Å and 5875 Å of A.1.
- Figure A.4. Spectrum of the He-Ar plus Ne lamps obtained with the 300 gpm grating through the 1×3 arcsec apertures. The L-42 filter was inserted to block second-order UV light.
- A.5. He-Ne-Ar spectrum in the far red. This spectrum was obtained with the Red Channel. An LP-495 filter was used to block second-order light shortward of about 5000 Å.
- Figure A.6. UV spectrum of Hg-Cd plus He-Ar lamps. Note that the Hg-Cd needs to warm up for several minutes before attaining full intensity. This spectrum was obtained with the 832 gpm grating and CuSO4 filter.

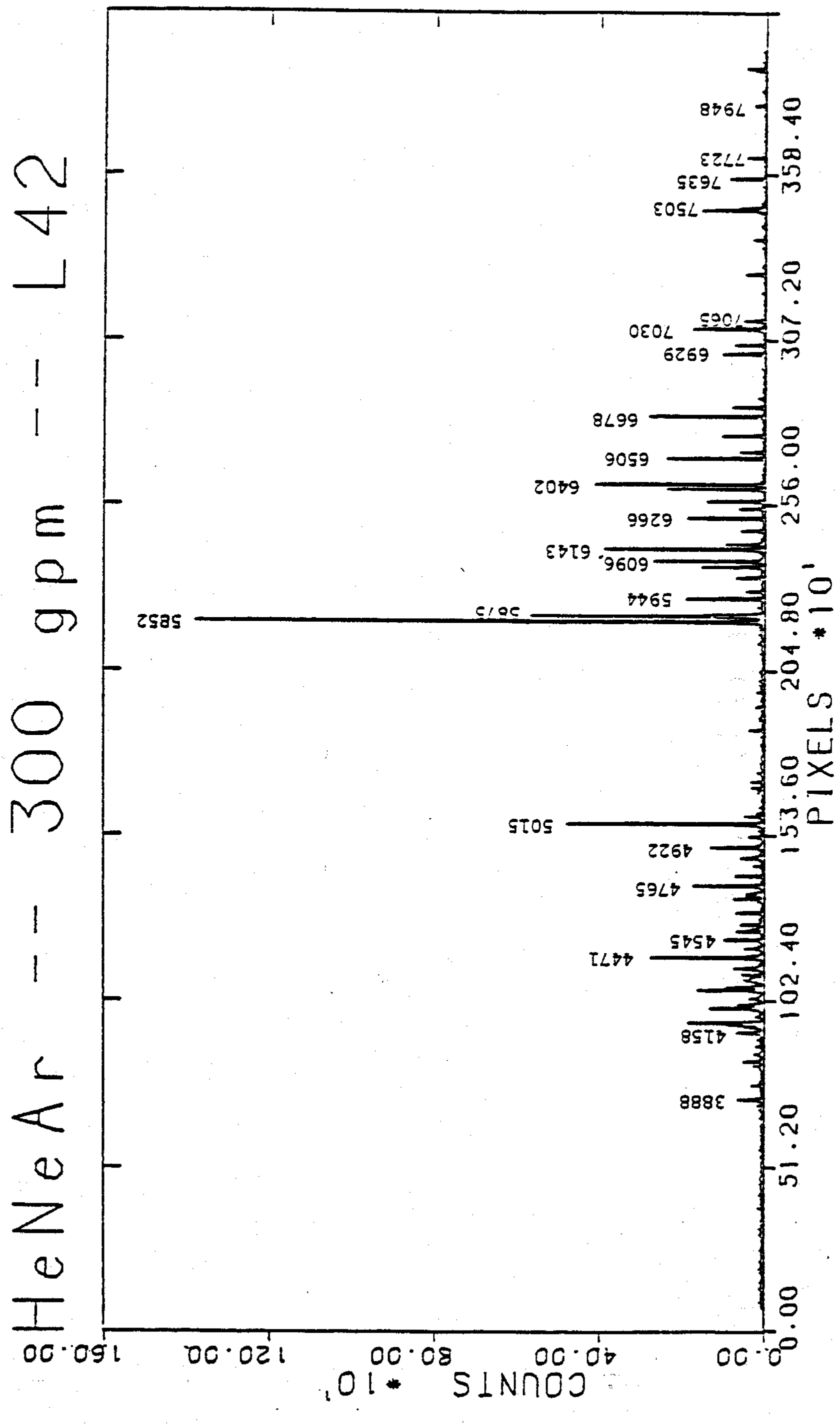
- Figure A.7 to A.10. 300 gpm spectra of: A.7 Hg-Cd, A.8 He-Ar, A.9 Ne, and A.10 He-Ar-Ne-Hg-Cd. See the other figures for line identifications.

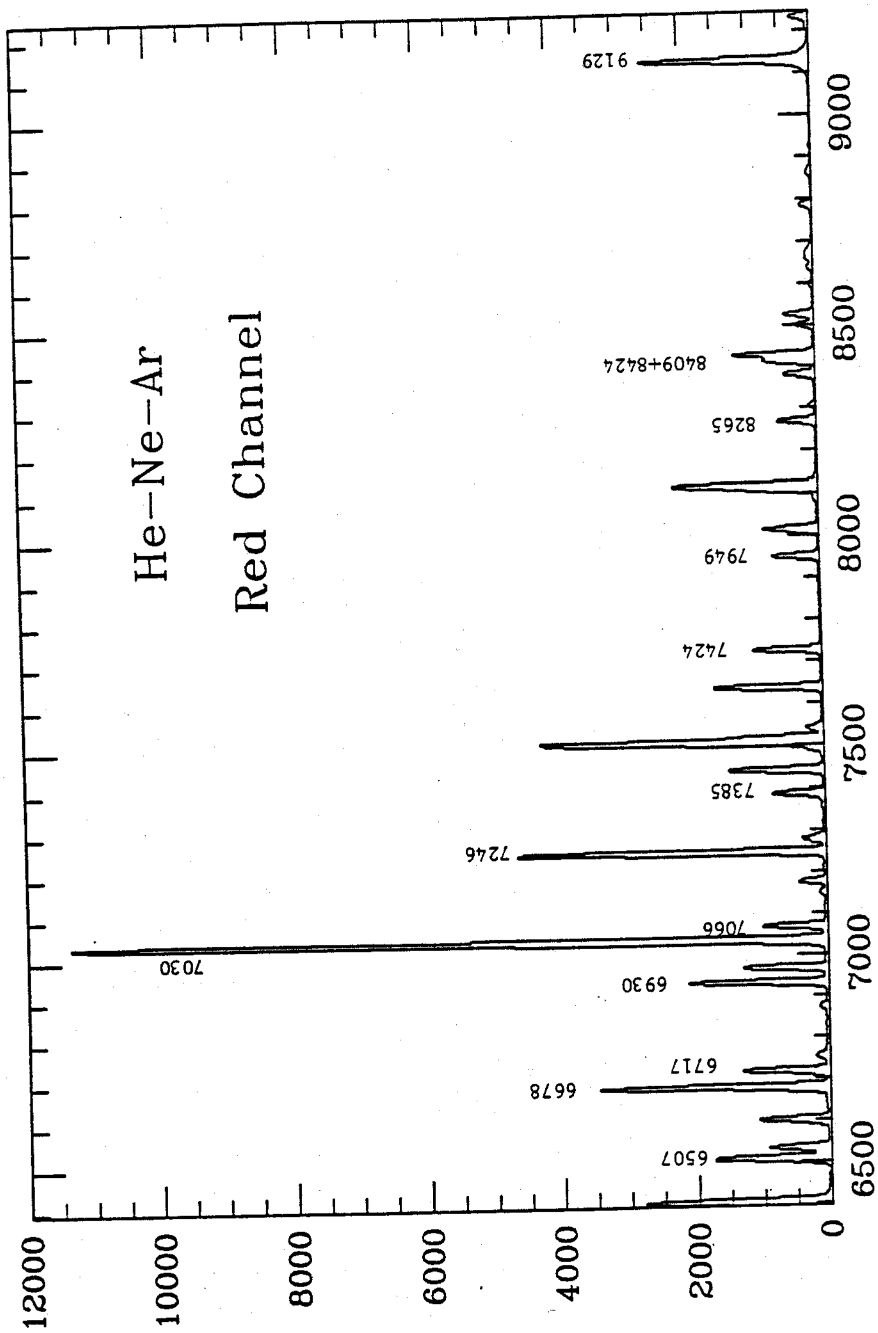


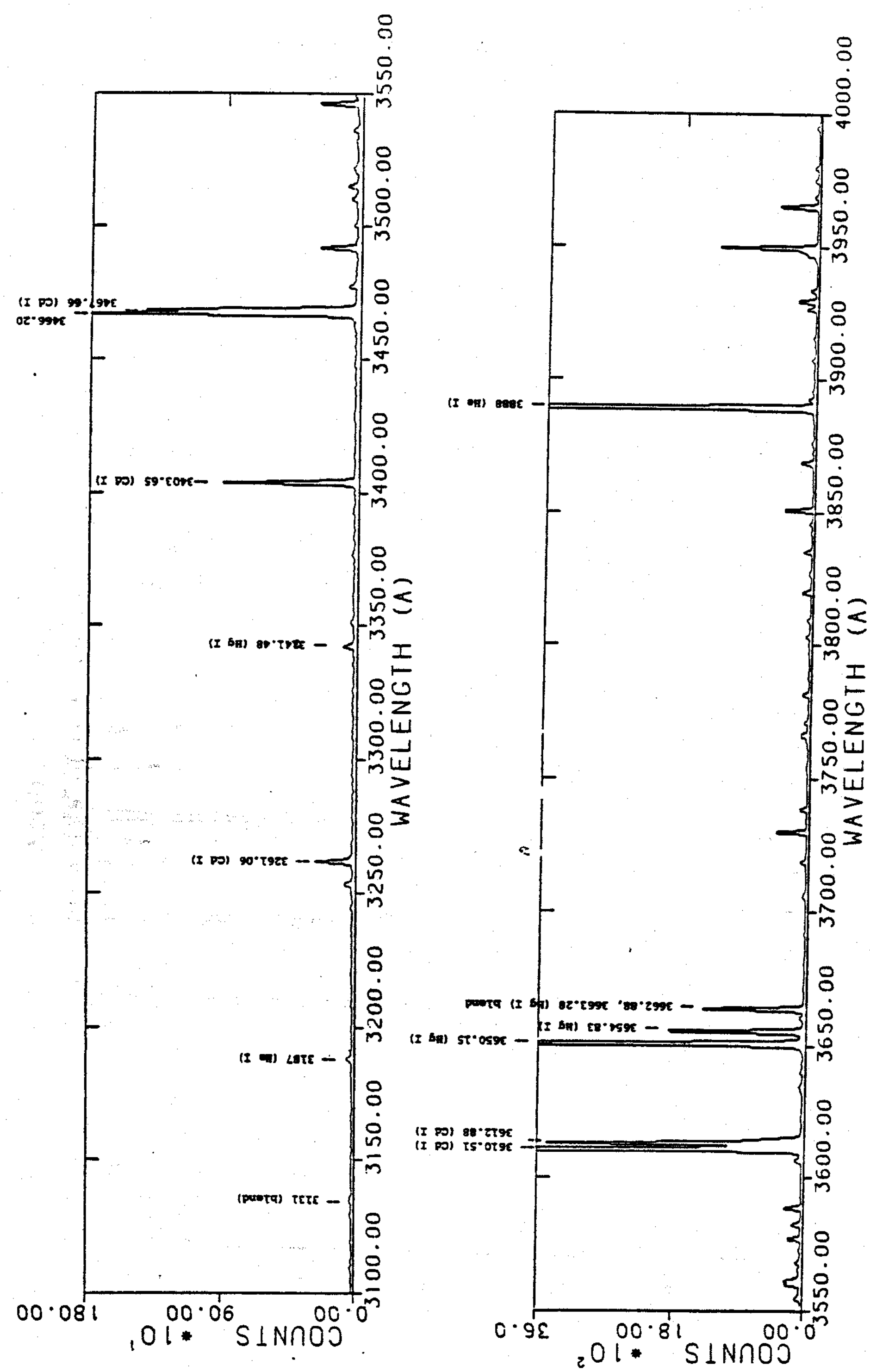
Helium-Argon -- 300 gpm
3491
3729
3888
4044
4158
4471
4545
4765
4922
5015
5875
6678
6965
7065
7503
7635
7723
7948
0.00
51.20
102.40
153.60
204.80
256.00
307.20
358.40
PIXELS *10'
0.00
10.00
20.00
30.00
40.00
COUNTS *10²


He-Ar -- 300 gpm
PIXELS *10¹
COUNTS *10¹
0.00
25.60
51.20
76.80
102.40
128.00
153.60
179.20
0.00
60.00
120.00
180.00
240.00
3187
3491
3729
3888
3949
4044
4158
4300
4471
4545
4657
4765
4806
4880
4922
5015
5162
5495


He-Ar -- 300 gpm
4965
5015
5162
5187
5221
5253
5495
5572
5650
5875
6032
PIXELS *10¹
COUNTS *10¹
145.00
155.00
165.00
175.00
185.00
195.00
205.00
215.00
225.00
235.00
0.00
15.00
30.00
45.00
60.00

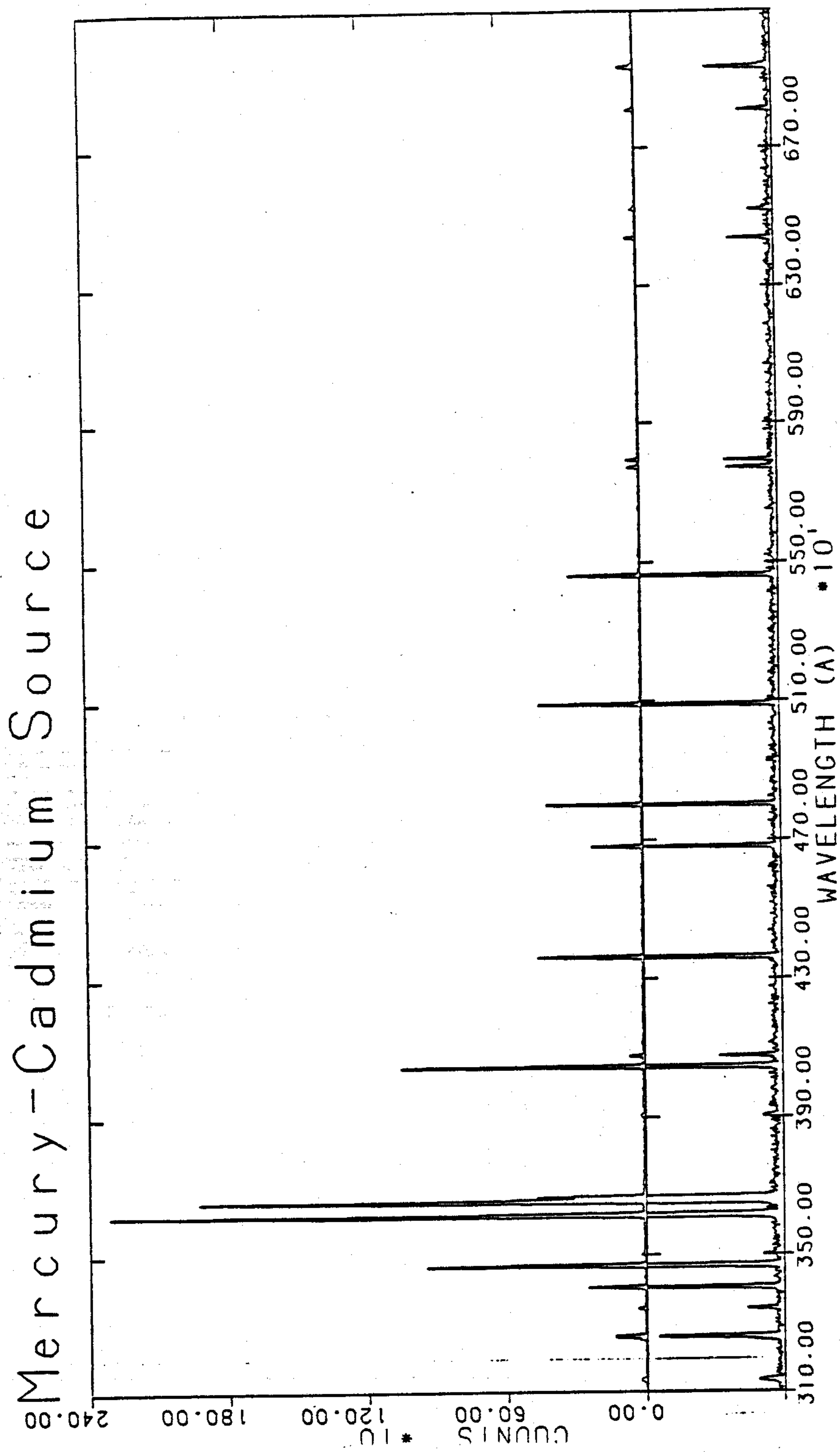

HeNeAr -- 300 gpm -- L42
PIXELS *10'
0.00
51.20
102.40
153.60
204.80
256.00
307.20
358.40
COUNTS *10'
0.00
40.00
80.00
120.00
160.00
3888
4158
4471
4545
4765
4922
5015
5852
5875
5944
6096
6143
6266
6402
6506
6678
6929
7030
7065
7503
7635
7723
7948

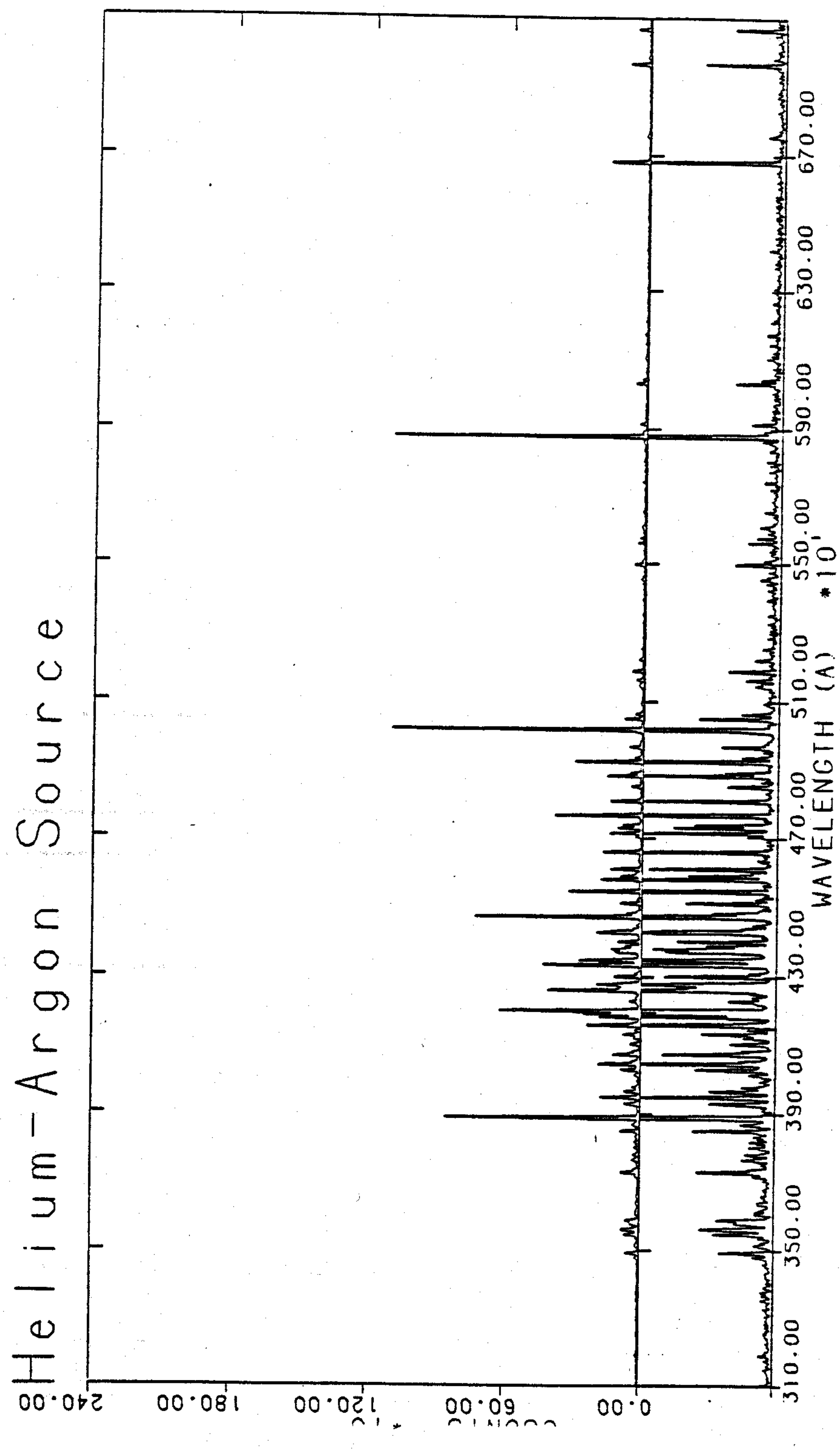

He–Ne–Ar
Red Channel
6507
6678
6717
6930
7030
7066
7246
7385
7424
7949
8265
8409+8424
9129
6500
7000
7500
8000
8500
9000
0
2000
4000
6000
8000
10000
12000

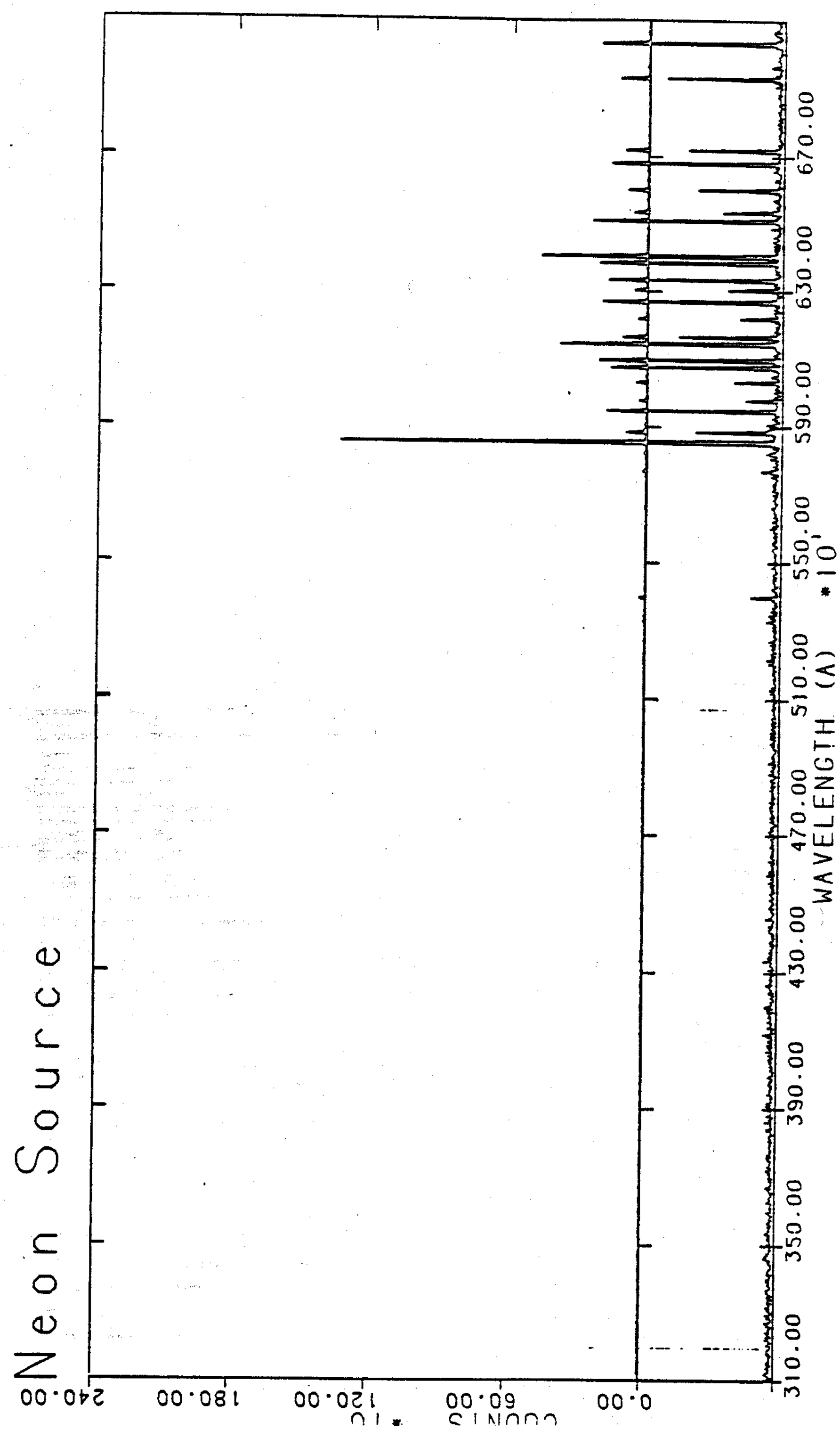


WAVELENGTH (A)
COUNTS * 10^1
COUNTS * 10^2
3467.66 (Cd I)
3466.20
3403.65 (Cd I)
3341.48 (Hg I)
3261.06 (Cd I)
3187 (He I)
3131 (blend)
3888 (He I)
3662.88, 3663.28 (Hg I) blend
3654.83 (Hg I)
3650.15 (Hg I)
3612.88 (Cd I)
3610.51 (Cd I)

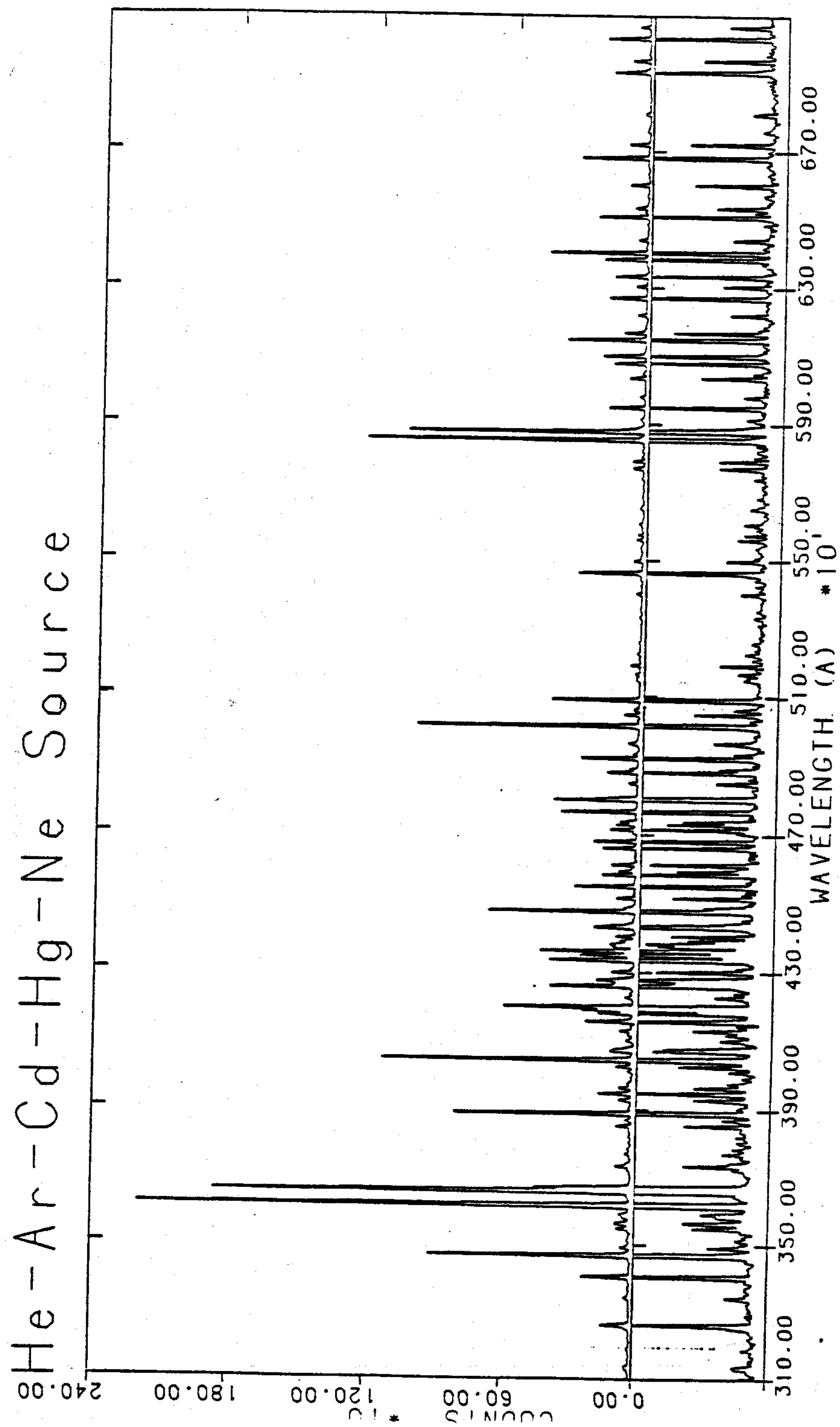
FIGURE A2-7


Mercury-Cadmium Source
WAVELENGTH (A) *10[1]
310.00
350.00
390.00
430.00
470.00
510.00
550.00
590.00
630.00
670.00
COUNTS *10
0.00
60.00
120.00
180.00
240.00


Helium-Argon Source
WAVELENGTH (A) *10¹
310.00
350.00
390.00
430.00
470.00
510.00
550.00
590.00
630.00
670.00
0.00
60.00
120.00
180.00
240.00



Neon Source
COUNTS *10
0.00
60.00
120.00
180.00
240.00
310.00
350.00
390.00
430.00
470.00
510.00
550.00
590.00
630.00
670.00
WAVELENGTH (A) *10[1]


He-Ar-Cd-Hg-Ne Source
240.00
180.00
120.00
60.00
0.00
310.00
350.00
390.00
430.00
470.00
510.00
550.00
590.00
630.00
670.00
WAVELENGTH (A) *10¹

Appendix B

Resolution versus Aperture Size

B.1 Blue Channel

Figures B.1 and B.2 present a comparison of emission-line profiles from the Helium-Argon comparison source illuminating the spectrograph through the double apertures available in the aperture wheel. In order to facilitate evaluation of the resolution in each case, a closely-spaced doublet was selected. The two lines have wavelengths (in air) of 4198.32 and 4200.67 (red is to the right in all panels). The integrations used to obtain these exposures were not of equal length, nor were they all taken with the same filtration. The spectrograph was focused with the Hartmann technique before the integrations were taken.

The apertures used in the panels of Figure B.1 were:

Panel a: Image Stacker

Panel b: 1×3 arcsec Double Slits

Panel c: 1 arcsec Double Circular Holes

Panel d: 1.4 arcsec Double Circular Holes

Panel e: 2×3 arcsec Double Slits

Panel f: 5 arcsec Double Circular Holes

Since the lines in Panel f are unresolved, two unblended lines observed with the 5 arcsec Double Circular Holes are presented in Figure B.2

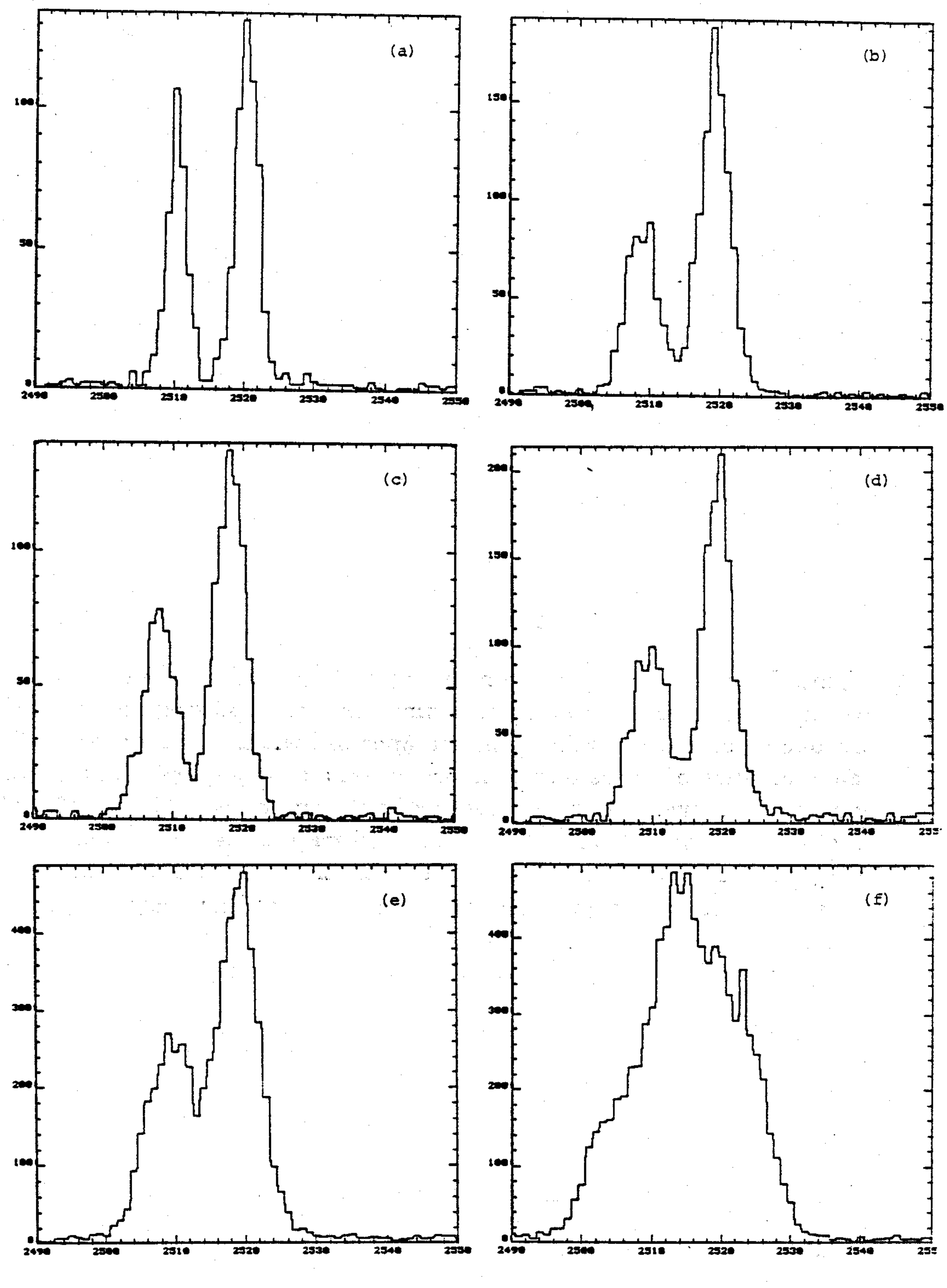


Figure B.1: Resolution vs. aperture size — Blue Channel

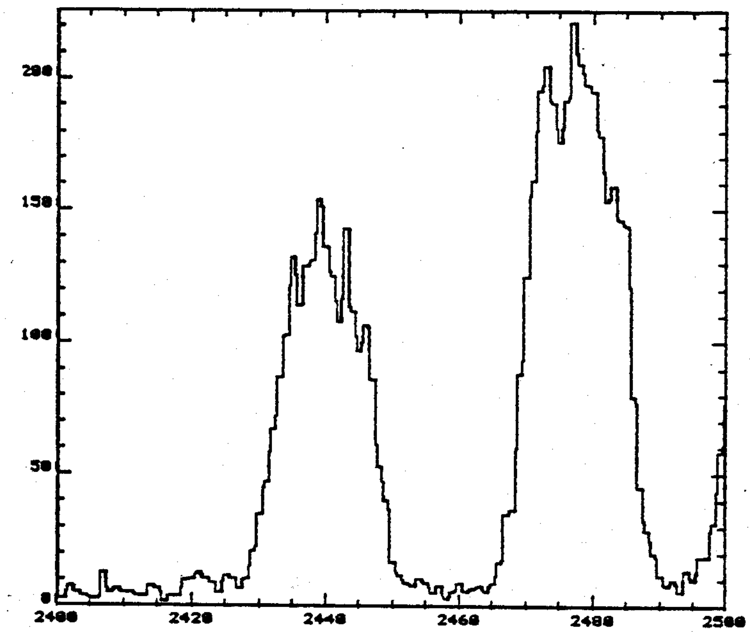


Figure B.2: Resolution vs. aperture size — Blue Channel

B.2 Red Channel

In Figure B.3 we present profiles of the He I λ5875 line observed with the Red Channel using the 1200 gpm grating in first order. The slits used in each panel were: (a) 1.25 arcsec slit, (b) 1.5 arcsec slit, (c) 2.0 arcsec slit, and (d) 5.0 arcsec slit.

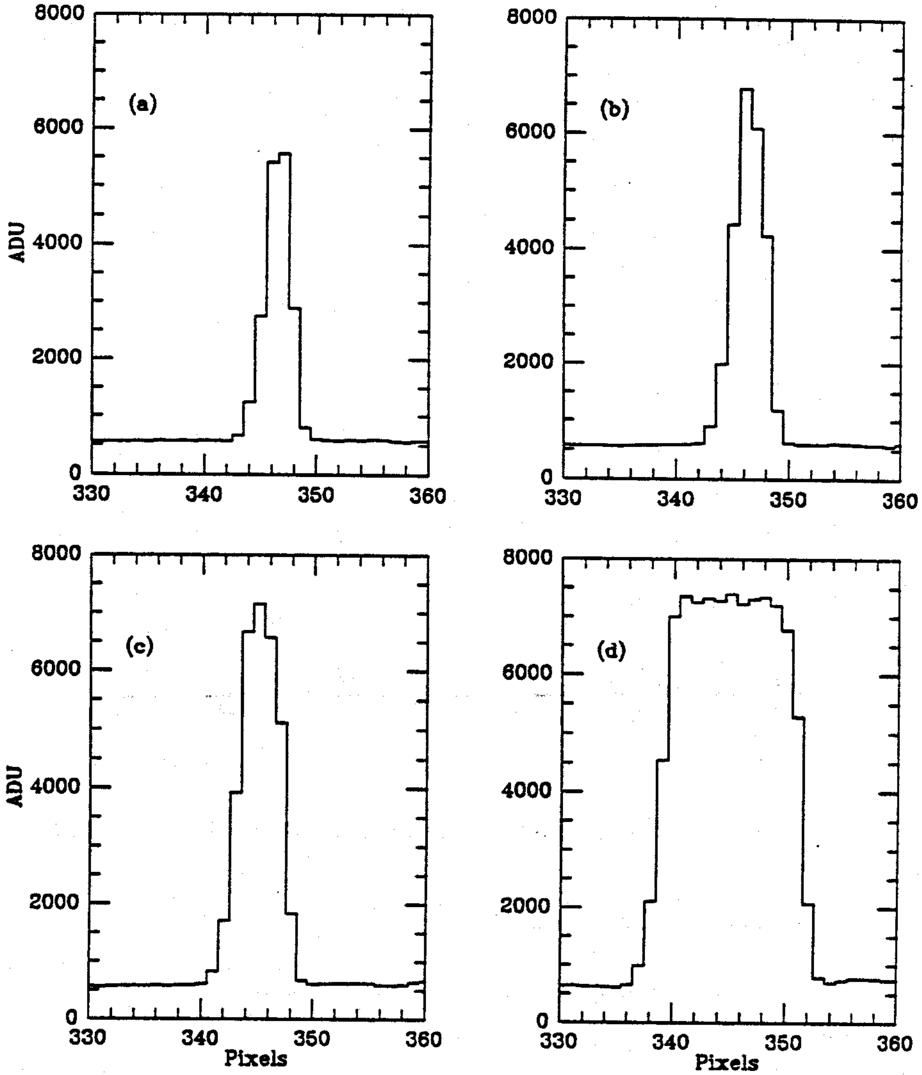


Figure B.3: Resolution vs. aperture size — Red Channel

Appendix C

Filters

Transmission curves for filters which are MMTO property are reproduced below. Be aware of two unfortunate circumstances:

1. Due to the restrictions on the number of filters which can be mounted in the upper and lower filter wheels (about 12), not all filters can be mounted at any given time.

2. The spectrograph must be removed from the telescope in order for the filters to be changed. Therefore, filter changes during a spectrograph run are strongly discouraged.

If you have any unusual requests for filters or if you would like a special filter mounted in one of the wheels, contact the Instrument Scientist or Instrument Specialist well in advance of your run.

Filters which will usually be mounted in the spectrograph and Top Box are listed below. Note that Top Box filters cannot be inserted into the sky beam, only the comparison beam.

Spectrograph Filters

Upper Filter Wheel	*Lower Filter Wheel*
Copper Sulfate (solid)	Dark
L-42	UV-36
R-63	U340
LP-495	1.25 mag. N.D.
	2.5 mag. N.D.

Top Box Filters

Top Box Filter Wheel	*Hartmann Filter Wheel*
Clear	Clear
0.3 N.D.	2.0 N.D. + Hex
mod 0.6 N.D.	Left Hex Hartmann
1.0 N.D.	Right Hex Hartmann
1.3 N.D.	Open Hex
1.6 N.D.	Left Hartmann
2.0 N.D.	Right Hartmann
Dark	Dark

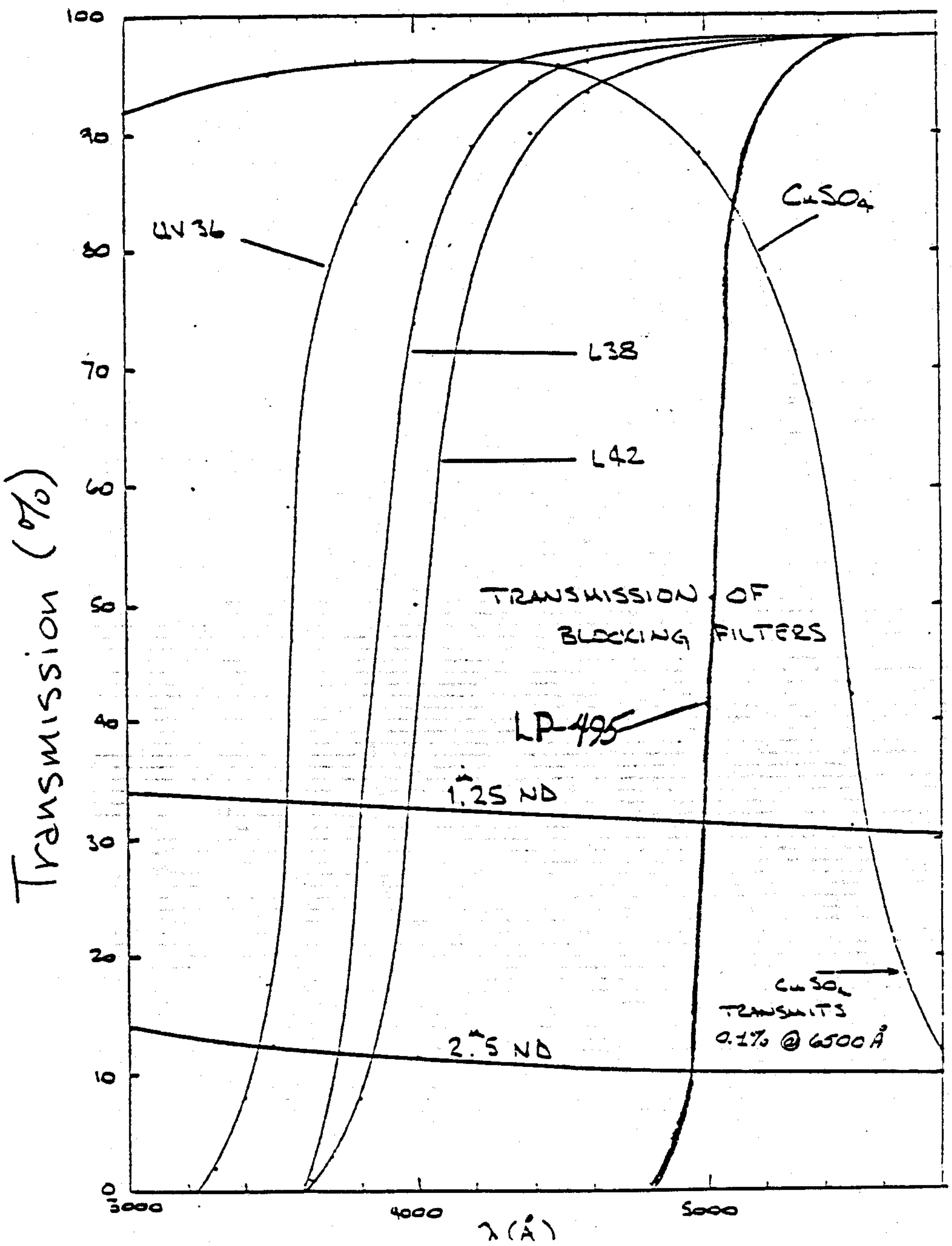


Figure C.1: Order blocking filters

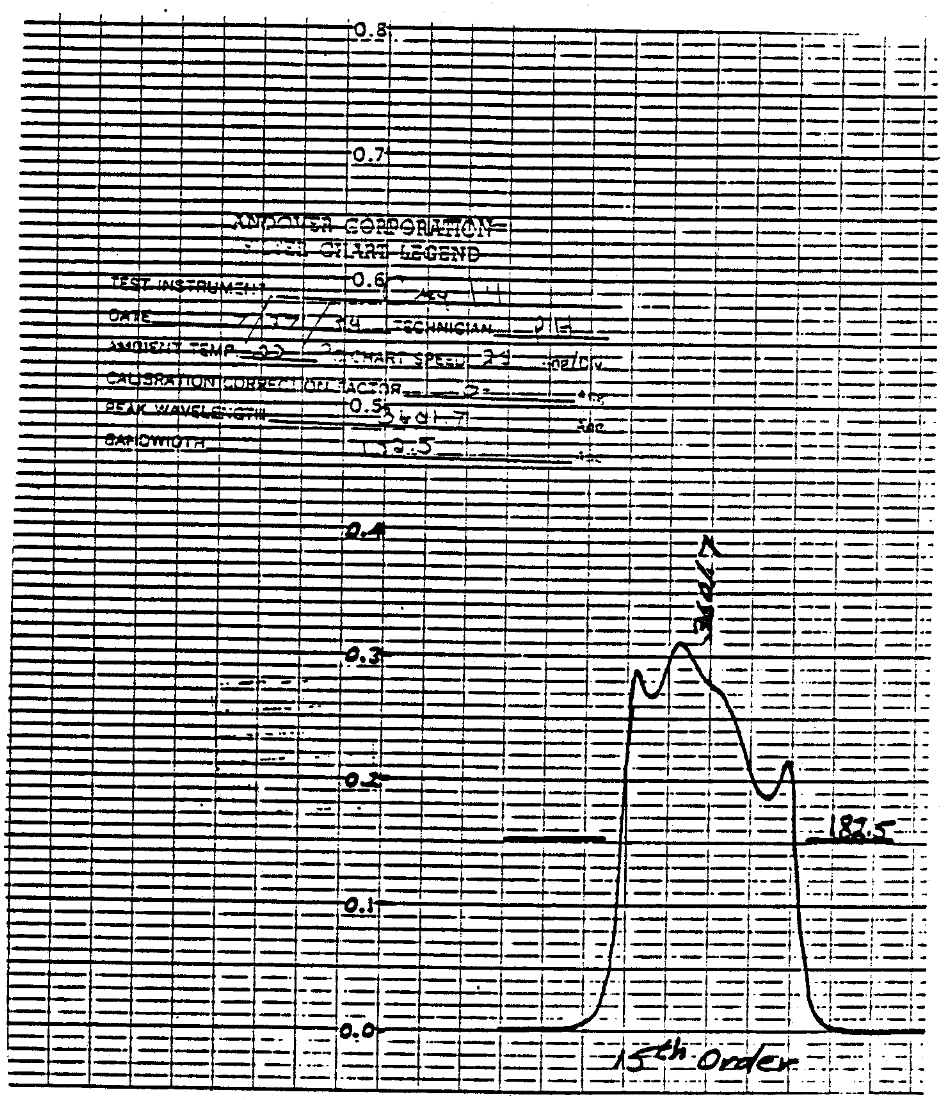


Figure C.2: 15^{th} order Blue Channel echellette filter.

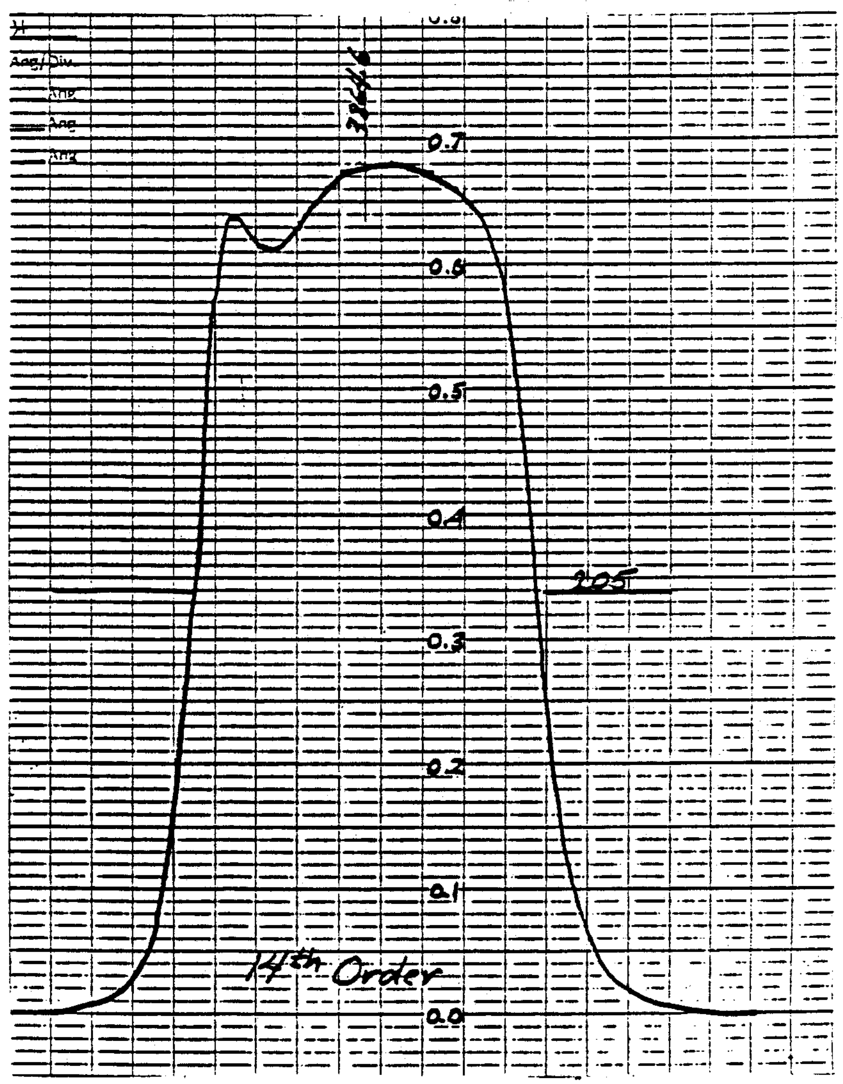


Figure C.3: 14^{th} order Blue Channel echellette filter.

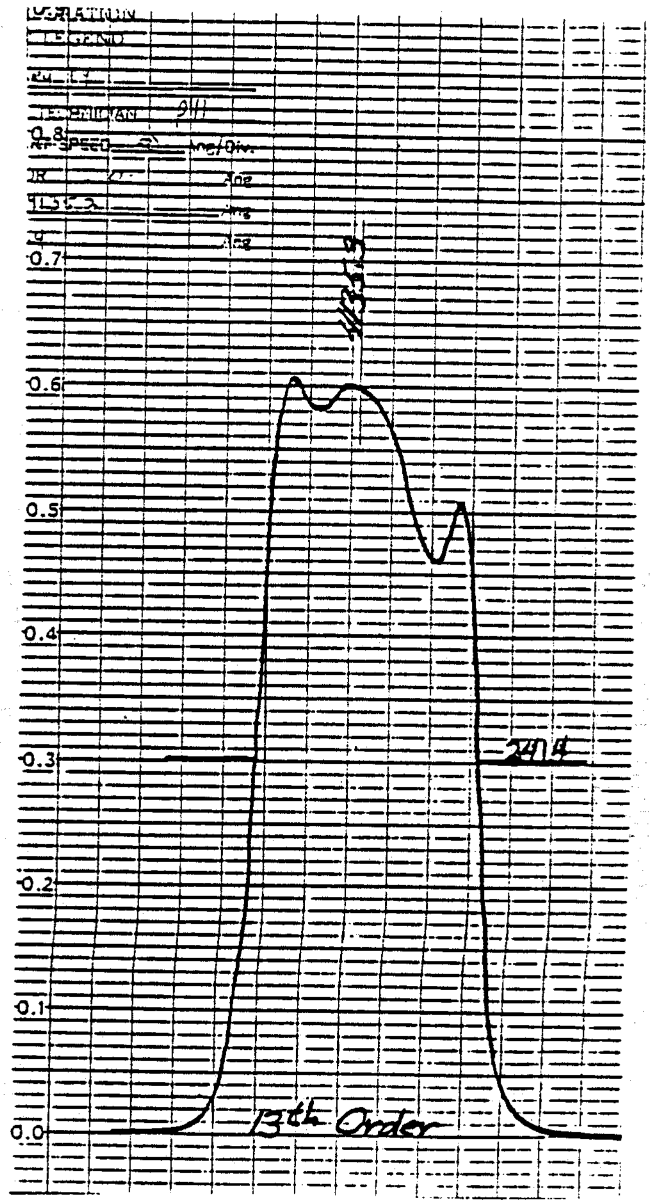


Figure C.4: 13th order Blue Channel echellette filter.

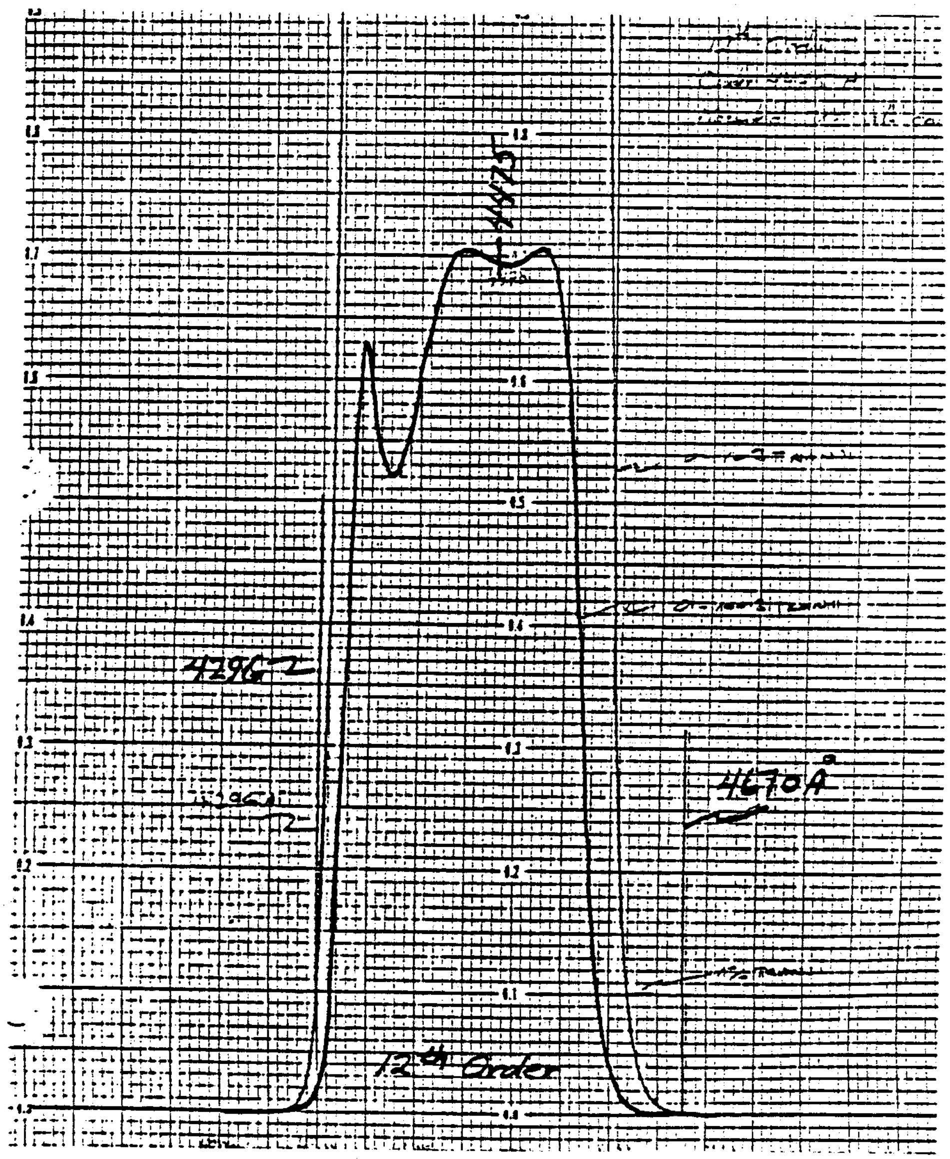


Figure C.5: 12th order Blue Channel echellette filter.

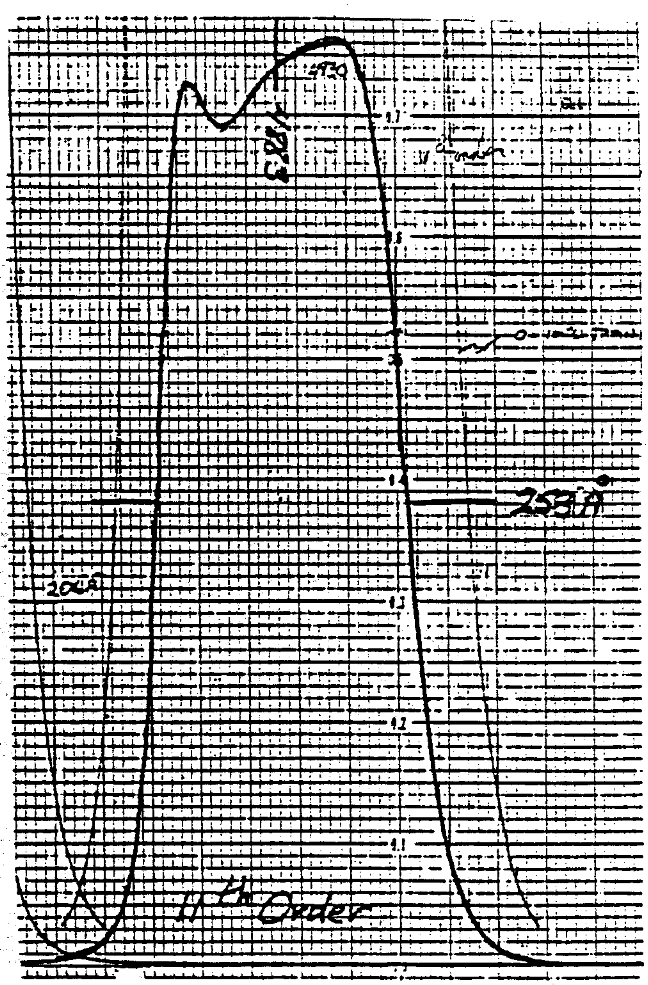


Figure C.6: 11th order Blue Channel echellette filter.

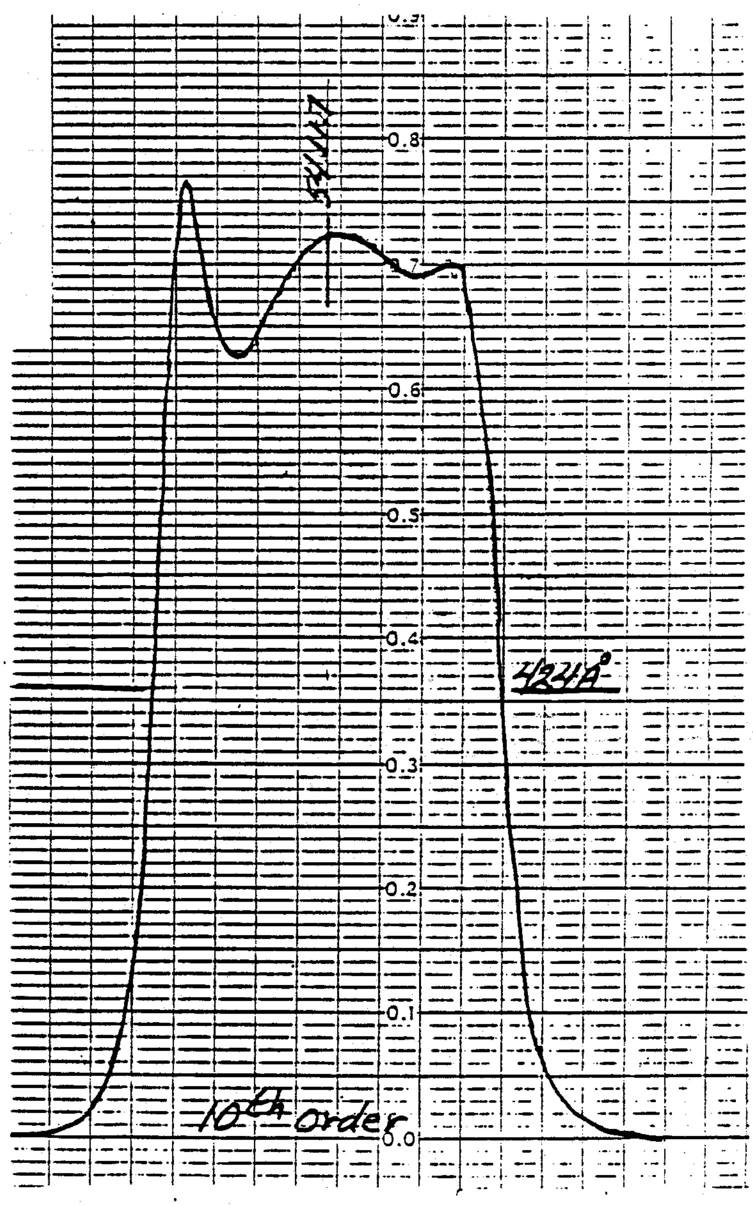


Figure C.7: 10^{th} order Blue Channel echellette filter.

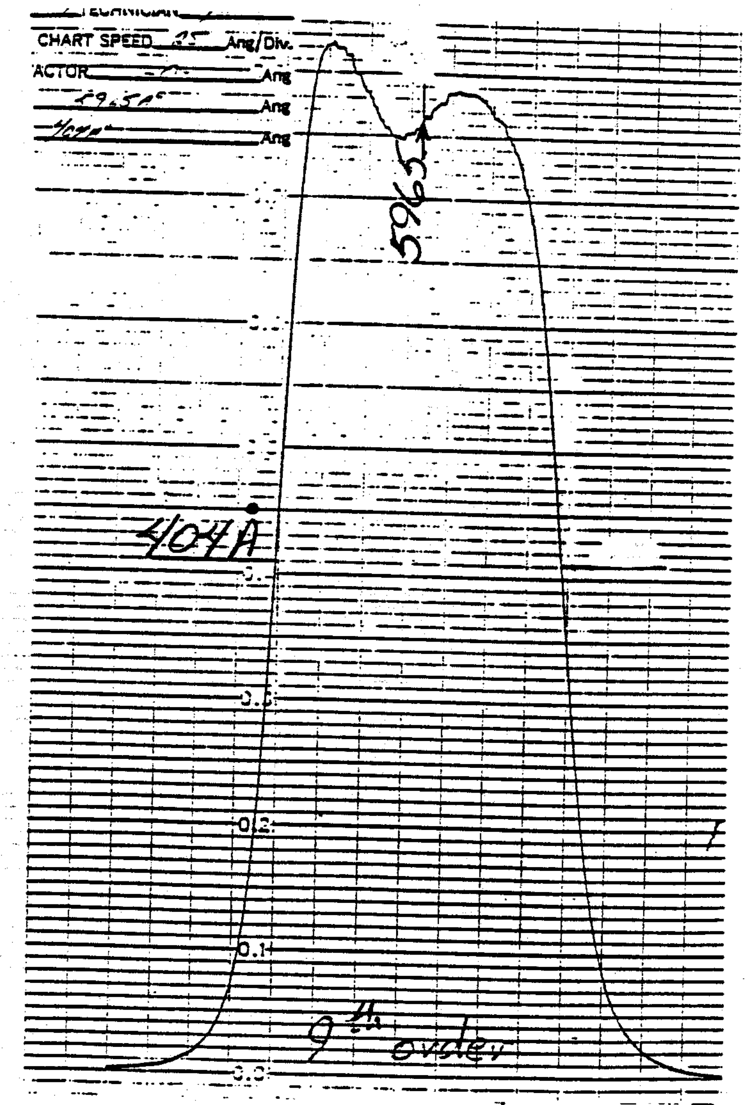


Figure C.8: 9^{th} order Blue Channel echellette filter.

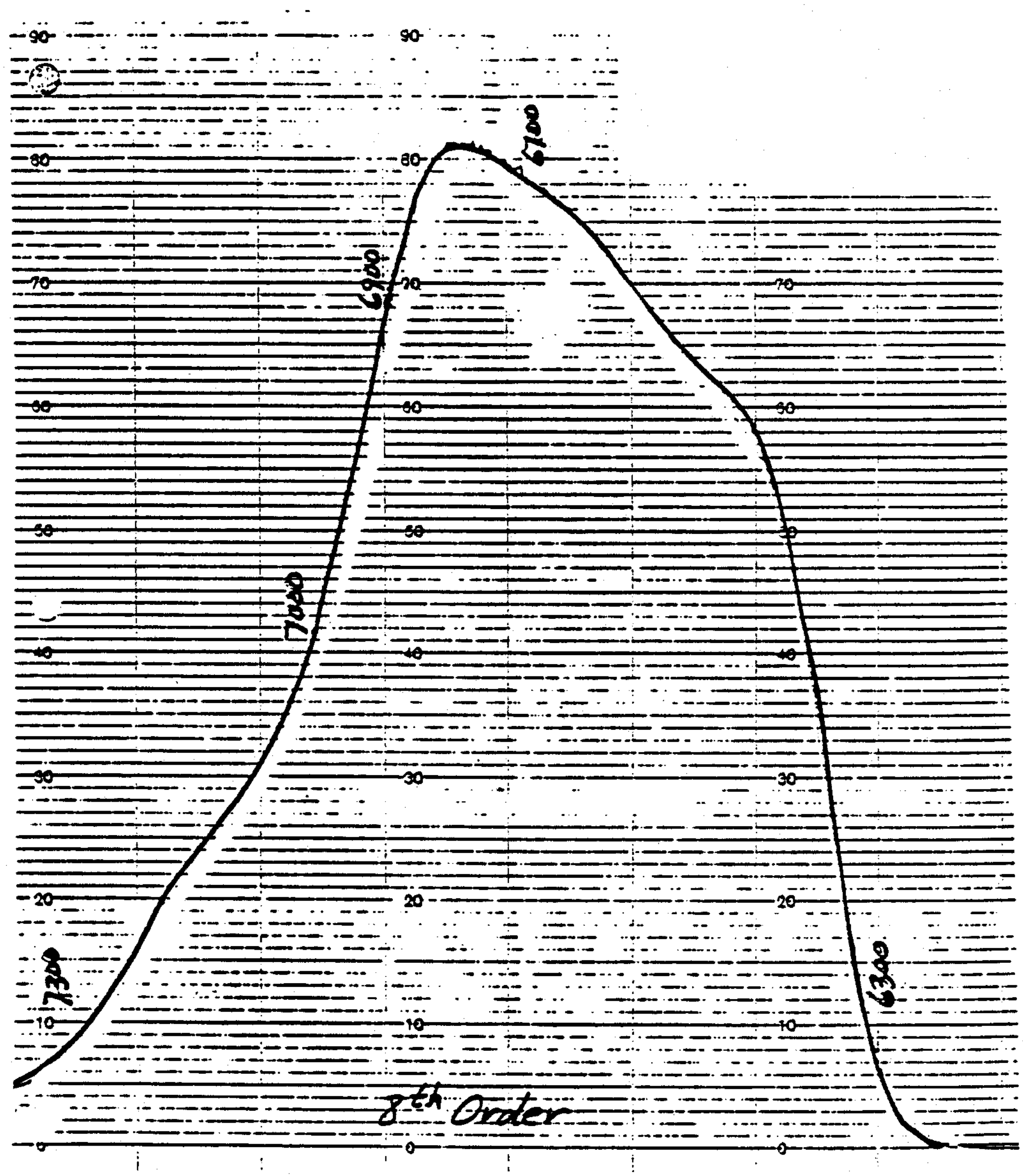


Figure C.9: 8th order Blue Channel echellette filter.

Appendix D

Computer Bootup Procedures

D.1 BCCS/RCCS IBM PC

1. If computer is not running, turn on PC AC power switch. After memory check is completed, computer will boot from the hard disk. Proceed to step 3.

2. If computer is running, hold down `Ctrl` and `Alt` keys with left hand and hit the `Del` key (on numeric keypad) with right hand. Computer will boot from its hard disk.

3. You do not need to fill in the time and date when prompted. Hit `Return`.

4. Type `BCCS` to startup the Blue Channel control program, `RCCS` for the Red Channel. Hit `Return`.

5. You will be asked if you want to control the Top Box functions. Answer `N` if you wish to use the Observer's Paddle, `Y` if you are running remote.

6. You will be asked if you want a cold or warm start. In a cold start, all motors are accessed and moved slightly. In a warm start, the last spectrograph configuration is adopted. In general a warm start is adequate.

7. The program will now initialize and present you with the `Command:` prompt.

D.2 Reticon Software

If all the instrument computer equipment has been turned off, start with Step 1; if only a reboot is in order, go to Step 7. If the power has been disconnected due to a power problem or thunderstorm find an MMTO staff person to reconnect the power. If none are available, connect the Hubble connectors at the backs of the racks and AC to Trident into AC outlet in the nearby rack. Turn the AC switch to *ON* in back of Trident.

1. Turn Point 4 key to ON.
2. Turn two expansion chassis power supply switches to ON.
3. Turn Grinnell internally illuminated green power switch to ON.
4. Load the disk pack if necessary and flip the Trident STOP/START switch UP. When the green light is on and has stopped flashing, disk access is permitted.
5. Floppy disk drive power switch to ON.
6. Insert appropriate floppy (marked with something like "CfA Reticon Data Collection System") into Drive 0. Ready and Track 0 lights must be ON. If this condition is not met, open Drive 0 door and then close. Both lights should now be ON.
7. Hit STOP and then APL on the Point 4 chassis.
8. Type `P33` on the TTY and hit a `Return`. Program will load. If not, flip the Up/Down switch and retry.
9. You must now respond as follows:

   Remember-ZEEGO or ZINIT

   `ZEEGO`

   enter vol#, 0-1 `0` (No `Return`)

   enter password `Z-MACH` *OK*

   The `Z-MACH` will not be displayed on the screen for obscure historical reasons. You must enter it in uppercase characters; if you do not enter exactly `Z-MACH`, then the system will respond with

   easy does it; try again

removing PWOV.3, linking system?

You must then enter ZEEGO and proceed again. Assuming you get an ok indicating you have entered the password correctly, some more text will be displayed, ending with the message

Last data subdirectory on this disk pack is MMMM where MMMM is an integer. MMMM will be the last directory you can use before a new Trident disk pack must be mounted.

10. The system is now up and running but requires four initialization commands before you are ready to start recording actual data.

    (a) Enter: `MM DD YY TODAY` where `MM`, `DD`, `YY` are month, day, year (e.g. 9 3 83 for Sept. 3, 1983). Note that the date is the current date for Tucson time, not the UT date. It will automatically change at midnight.

    (b) Next enter: `HH MM SS HOUR` where HH MM SS is the 24-hour MST at the instant you hit `Return`.

    (c) Locate the notebook labeled *Reticon Data Log/Current* and find the directory number of the last sheet. You may begin using the current directory number, or if it is nearly full begin with the next directory. In either case, if NNNN is the disk number you wish to begin recording your data in, then enter

        `NNNN TLINK`

        `?DISK` *DISK=NNNN*

        Select the appropriate comparison lamp id and comment template by typing `HE-AR` or `HENEAR`

    (d) If you are recording your data in 8K mode (i.e. two 4096-pixel spectra per exposure), you should now issue the command `8K`.

The Reticon Software system is now ready to record data.

D.3 CCD Software

Ensure that the Diablo disk drive is powered up and the Ready light is lit. Also ensure that the Point 4, Grinnell, tape drive, CCD controller and CCD power supplies are powered-up. If the system has been running (i.e. following a crash), carry out step 1. If not, proceed to step 3.

Note that this process has caused considerable confusion. In Step 2, all of the 0's are *zeroes*, not *ohs*.

1. Push STOP, then APL on the Point 4
2. Enter the following on the terminal:

   `0:61133` followed by a return. The computer will respond with `1:`

   Enter `63077` followed by a return. The computer will respond with `2:`

   Push `Esc` on the terminal.

   Enter `C0,141400` followed by a return.

   Enter `J0` followed by a return. The return will not be echoed.

3. Push APL on the Point 4.
4. Enter the following on the terminal (each line is followed by a return).

```
P33

FORTH

3 LOAD

77776 SYSGEN

3 LOAD

MMT LOAD
```

5. After a few interminable moments, the status display will appear. set the date and time (MST) with the `DATE` and `TIME` commands. Set the mode to S with the `MODE` command.

In the RCCS system, `Alt-R` sends the string sequences in 3 and 4 to the Point 4. One must still manually depress the APL button, so unless you have a friend who will go up to the computer room to push the button, you may be better off just typing them by hand.

After a crash one must reset the binning parameters (e.g. `1 800 2 SETUP 2 VBIN` for 2×2 binning) and mount the tape with `0 UNIT LOAD-TAPE` *taking care not to re-initialize it.* That is, answer `N` when asked if this is a new tape.

Appendix E

Special Procedures

Note: The following procedures are normally carried out by the Instrument Specialist, Instrument Scientist, or Telescope Operator. They are documented here in case the observer needs to carry them out in a pinch. **Just because they are written down does not mean that you should attempt them without explicit authorization from the Instrument Specialist or Instrument Scientist.**

E.1 Reticon Detector Power-up

The front end of Big Blue is essentially irreplaceable. Therefore, all the precautions and procedures described here and elsewhere in this manual dealing with Big Blue must be strictly adhered to. The following sequence must be followed exactly.

E.1.1 Solenoid Power

1. Ensure that solenoid cooler is running. Consult the Instrument Specialist for details.

2. Go to the computer room. The power supplies are in a rack opposite the instrument computer. Turn on the digital ammeter switch. Liquid crystal display should come on.

3. Make sure that the current and voltage knobs on the HP solenoid power supply are all the way down (turned to counter-clockwise limit).

4. Depress the Power push-button on the HP power supply.

5. Press the fault reset button on the digital ammeter panel. A relay should click and the current and voltage knobs will become enabled.

6. Slowly turn on both the current and voltage, alternating knobs as first the voltage-limiter and current-limiter circuits control the power supply. In the operating configuration, the power supply must be in the "current" mode, indicated by the green light near the current meter. When the green light comes on near the voltage meter as you are turning up the supply, turn the voltage knob about one turn clockwise beyond the point where the green Current light comes on. Proceed in this way to the posted current setting. The current drifts during the first few hours so monitor it.

7. Make sure the Reticon head electronics power supply on the spectrograph is on as well as the Reticon discriminator chassis power. Both channels of the LED display on this chassis should come on and show 0 counts. Now proceed to high voltage turn on.

E.1.2 Image Tube Power

Before proceeding, make sure that the camera shutter on the spectrograph is in the closed position. *DO NOT attempt to bring up the voltage if the count rates are not being displayed on the discriminator LED read-outs.*

1. Make sure the output control knob on the front panel of the MCP power supply, (Spellman #5) is turned fully to 0.0 (counterclockwise to the limit).

2. Turn on the power toggle switch.

3. Hit the power reset button.

4. Slowly (0.5 kV/sec) turn up the voltage, till the knob reads the value posted. *Set by the knob, not the meter! Do not exceed this value Under any circumstances.* No counts should appear on the LED displays; if they do, slowly turn down and off the MCP supply and call for help. If the meter does not increase as the knob is increased, turn down the knob to 0.0, turn off the toggle switch, repeat steps 2 and 3.

5. When the voltage is up, check the mA current. The meter sticks and may need to be tapped. It should read the value posted on the meter. If it is zero or above 0.7, turn off the MCP and call for help.

6. Make sure the output control knob on the front panel of the three-stage power supply, (Spellman #4) is turned fully to 0.0 counter clockwise). Make sure there are no notes indicating the power supply polarity has been changed.

7. Turn on power supply toggle switch of Spellman #4.

8. Hit power reset button on Spellman #4.

9. Turn up the high voltage control knob *slowly* at the rate of 0.5 kV/sec until you reach a voltage of 25 kV. At any point during this time the LED displays should never exceed 3-4 counts and should be at 0 until 22 or 23 kV. At 25kv, pause and verify that a few counts/sec (~ 10) are being displayed. If this is not the case *do not proceed.* Call for help.

10. Continue to turn up at the same slow rate to the posted value. Again, set by the knob and not by the meter. Don't confuse the MCP and ITT setting.

11. Monitor the dark count rate for a minute or so to verify there are not bursts of counts above the normal dark of 10-40 for the cooled tube.

E.1.3 Turning the System Off

1. Turn down slowly (0.5 kV/sec) the magnetic 3-stage power supply; turn off toggle switch.

2. Turn down slowly (0.5 kV/sec) the MCP power supply; turn off toggle switch.

3. Turn down the solenoid current to zero; turn off AC power to solenoid supply

4. Turn off Reticon camera electronics, or, if desired, leave it on. But be certain it's on and functioning before turning back up the intensifiers

5. Turn off solenoid power.

E.1.4 Power Interruption

In the event of a mountain quiet power interruption, the following should happen: (1) The Spellman power supplies for the MCP and 3-stage high voltage will shut off and stay off. This will also occur if the overillumination sensor turns off the Spellman HV power. (2) The HP power supply current to the solenoid will shut off. If you are at all uneasy about putting power back on the tubes, call for help. (3) The image tube cooler (Neslab ULT-80) will turn off and will not restart until manually reset.

1. The ULT-80 is located in the third level Instrument Lab. Above the unit is a gray box called the Cooler Interface Unit. If the power has been off for a short time, and the image tube temperature has not risen above −20° C, simply open the interface cover and push the *contactor close* pushbutton. If power has been off for a substantial time, or if the image tube temperature is above −18° C, or so, call for assistance.

2. Turn solenoid current down, reset the solenoid current by pushing the black reset button of the gray box adjacent to the HP power supply, and turn current back up to its nominal setting. Check the solenoid current setting, which is posted near the HP power supply.

3. First turn to zero the MCP Spellman HV OUTPUT control knob and then push its reset button. Then bring back up the high voltage as per above.

4. First turn to zero the 3-stage Spellman HV OUTPUT control knob and then push its reset button. Then bring back up the high voltage in the manner described above.

NOTE: If additional power interruptions appear likely, e.g. due to lightning or system failures, do not bring up the image tube high voltage.

E.1.5 Solenoid Overtemperature Fail-safe

In the event the solenoid becomes dangerously hot (e.g. if cooling fails), a thermostat in the solenoid activates the overtemperature fail-safe box, which shuts off the solenoid current. The only warning presently that this happens is that the count rate will go down and the images will become defocused. If this happens:

1. Turn down (slowly) the 3-stage and MCP Spellman power supplies.

2. Turn off the Solenoid power supply and check the solenoid cooling. Call Ouellette or Cromwell if there are further problems.

E.2 Blue Channel Grating Change

1. *Turn off the image tube power.*

2. Close the camera shutter.

3. Suspend SCCS and run the program CHANGE. Set the grating tilt and turret to the values listed below under 'Cover' corresponding to the turret position containing the grating you wish to interchange.

   Note that the echellette grating barely fits through the hatch. Consequently, the tabulated values may need to be modified slightly.

Normal Gratings

Turret Number	*Grating Tilt*	*Turret for Cover Removal*	*Turret for Grating Removal*
I	4.0	7.60	8.66
II	4.0	4.40	3.65
III	4.0	5.20	6.18

Echellette Grating

Turret Number	*Grating Tilt*	*Turret for Cover Removal*	*Turret for Grating Removal*
I	3.5	7.80	8.435
II	4.0	4.16	3.48
III	4.0	5.20	6.175

4. Unscrew the three thumbscrews on the grating turret housing (east side of the spectrograph). The door will open on its hinge and you will be looking at the grating assembly. From this point on you will be dealing with the grating. Don't talk or chew tobacco when handling an uncovered grating. Do not touch the grating surface under any circumstances.

5. Insert the grating cover. Secure with masking tape. Be sure that the cutouts on the cover clear the counterweight struts.

6. Set the turret position to the value for grating removal listed in the table above.

7. Insert the knurled brass 1/4-20 screw into a tapped hole in the counterweight strut. This is a safety screw in case the grating is released prematurely.

8. Using a ball driver, loosen the four captive cap-head bolts in the grating cell flange which hold the grating into the turret. Be careful to support the grating with your other hand since there the grating will be unsupported when you remove the last bolt.

9. Slide the grating out along the counterweight struts. Remove the brass bolt when necessary.

10. When mounting a grating in turret positions I and III, the handle on the cover should be on the side of the cell at the tail of the arrow on the back of the grating indicating the blaze direction. When mounting in position II the handle should be on the head side. You may have to switch the cover on the new grating. This exposes the ruled surface – don't breathe while the grating is exposed.

11. Mount the new grating securing it into the turret with the four captive bolts. Make sure that the arrow on the back of the cell is pointing up (toward the ceiling). Tighten the bolts slowly, as if you were mounting a tire.

12. Move the turret to the tabulated position for cover removal, remove the grating cover, close the grating access door, and tighten the thumbscrews.

13. Put the old grating and brass bolt away in the cabinet in the spectrograph garage.

14. Exit the CHANGE program and reboot BCCS using a cold start. Modify the BCCS parameter file (see instructions later in this appendix) to reflect the grating change and note the change on the whiteboard.

15. The TIRP setting for the new grating must be calibrated before use. See instructions in Section 3.4.7.

E.3 Red Channel Grating Change

1. Position the grating to the stow position with the RCCS command `STOW`.

2. Loosen the four bolts holding the disperser cover flange. The cover you need to remove is labeled and the holes are keyed.

3. Twist the cover and remove it. You will be looking down the grating slide assembly. Slide position I is the farthest in. Hence, position III is the first accessible.

4. Using the grating removal tool ('Kal Kan'), remove the first grating. This is turret position III. Remove the grating by inserting the keyed end of the tool into the keyway under the grating cell. Rotate the tool 180 degrees and slide the grating out. Remove other gratings as necessary.

5. Install the new grating and any others that were removed. The labeled side of the gratings should face you. You will need to use the special tool to insert the gratings.

6. Reinstall the grating cover and tighten the bolts holding the flange.

7. Change the RCCS parameter file to reflect the change. The procedure is described below.

E.4 Changing the BCCS/RCCS Parameter File

Any physical change of the gratings, filters, or apertures of the spectrograph must be recorded in the parameter file in order for the control programs to be aware of the change. This is accomplished by the BCCS/RCCS command `PARAM`. To change the parameters:

1. Enter the command `PARAM`.

2. Enter the password. Foltz, Ouellette, and Poyner know it if you don't.

3. Follow the directions in the menus to make the change.

E.5 Red Channel CCD Shutter Insertion

Always insert the shutter before removing the TIRP from the beam.

1. Locate the shutter crank on the south side of the spectrograph. The crank is mounted on a panel with a cable jack.
2. To crank the shutter into the beam (for Red Channel use) turn the handle counterclockwise. Stop when you feel resistance.
3. To crank the shutter out of the beam (Blue Channel) turn the handle clockwise until it stops. You will feel some jitter.

E.6 Removing the TIRP from the Beam

Always insert the Red Channel shutter before removing the TIRP (see above.)

1. Important: Using SCCS or the CHANGE program, set the TIRP to 8.6.
2. Crank the tirp out of the beam using the crank marked 'Do Not Crank' on the north side of the spectrograph. Turn the crank clockwise to remove the TIRP and counterclockwise to insert it. If you feel undue resistance during the cranking operation, stop. *Do not exert undue force* – you will break a little chain and we will break both your femurs (at least).

E.7 Moving the Red Channel Camera for Cross-Dispersed Work

1. Loosen the cap screws around the perimeter of the cross-dispersing prism housing. Do not remove the screws; only loosen them. Have an associate hold the camera box during this procedure. If you don't, the camera box and dewar will swing free and scare the hell out of you.
2. Swing the camera box and dewar to the desired position. When going to normal mode, the camera should rest against a machined stop. In this mode the dewar will be pointing down at about a 45 degree angle.

For cross dispersed mode use the micrometer stop above the CCD camera box assembly. See Section 4.7.2 for details of the micrometer setting. dispersed mode the butt end of the dewar is elevated slightly above horizontal.

3. While your associate holds the camera box and dewar in place, tighten all the cap screws.

E.8 Filling the Red Channel Dewar

The hold time of the dewar is well in excess of 12 hours. Normally, the operator will fill the dewar. If there is evidence that the dewar is warming up, fill the dewar as follows.

1. Roll the 60 liter liquid nitrogen (lN_2) dewar near the back of the CCD dewar.

2. A rubber hose with a stainless tube should be attached to the output of the holding dewar. These should be labeled with a tag something like 'Red Channel lN2'. Insert the stainless tube into the fill hole in the back of the red channel dewar until it stops.

3. With a gloved hand, hold the tube in place while you open the "LIQUID" valve on top of the 60 liter holding dewar slowly with the other hand. Nitrogen will begin to flow. Soon the rubber hose will become stiff enough so that you no longer have to hold it.

4. Increase the flow rate slowly but make sure that the exhaust plume out of the fill tube is not longer than about two feet. Allow the nitrogen to flow until liquid runs out and hits the floor. Do not be faked out here – make sure that LIQUID is running out. Don't be surprised if a fill takes as long as 15 minutes or so — it depends on how wide you open the LIQUID valve.

5. When the dewar is fully charged, close the valve on top of the holding dewar. This will stop the flow.

6. If possible, remove the stainless tube by rolling the holding dewar away from the back of the spectrograph. If the tube is too stiff, wait until the rubber hose warms up and becomes flexible again. Make sure that the holding dewar is rolled well away from the bottom of the telescope where it cannot be hit by the OSS at low elevations.

7. Leave a note for the operator indicating the time of the fill.

E.9 Changing the Magnetic Aperture Plate

1. Make sure the Blue Channel image tubes are OFF.
2. Get the magnetic tool and desired aperture plate from the spectrograph storage cabinet in the lab.
3. Command the aperture assembly to the Magnetic position with the RCCS/BCCS command `AP MAG`. Wait for execution to finish.
4. On the south side of the spectrograph, the small central panel (above the shutter knob) has four thumb screws holding it in place. Remove the panel.
5. Insert the *empty* magnetic tool into the aperture hole. It only goes in one way. Wiggle it into place. (Yes, it is a tight fit, isn't it?)
6. Push the knob on the tool *down* until it stops, then release it.
7. Remove the tool from the hole. With luck, you will have removed the aperture plate.
8. Unload the old plate from the tool and load the tool with the new plate. *Keep your fingers off the reflecting surface of the plates.* When loading the tool, make sure the reflective side is flush against the tool.
9. Here's the tricky part: Notice that when you push the knob of the tool down, an aluminum bar is also pushed down. To separate the plate from the tool, you will need to lift the knob from the plate *while keeping the bar down.* Try it with the tool out of the spectrograph. Practice doing it one-handed. Proceed when you get good.
10. Insert the loaded tool into the aperture hole until seated.
11. Push down on the knob to set the aperture plate.
12. Separate the tool from the plate as described above.
13. Replace the side panel of the spectrograph.
14. Put the tool and old plate away, *making sure the plate goes into the proper envelope.*

15. Update the white board in the control room to let others know about the change.

16. Take a break, we are both going to ...