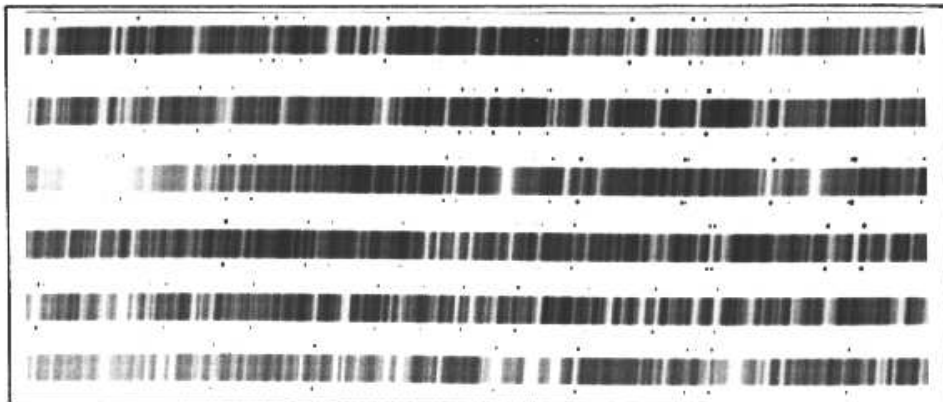


Instrumentation Operation Manual ECHELLE SPECTROGRAPH

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This manual describes the general design, setup, focusing, and operation of the Kitt Peak 4 m echelle spectrograph including use of CCD detectors. While this manual is intended for use by KPNO support staff and visiting astronomers, observers are cautioned not to attempt any of the adjustments described herein without prior approval of KPNO staff.



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1 Introduction

The Kitt Peak 4-meter echelle spectrograph is a versatile instrument capable of high resolution ($\leq 80,000$ or $\geq 0.07 \text{ \AA}$) over a wide range of wavelengths. Its two-dimensional format (cover figure) is ideal for array detectors. Cross dispersion gratings are available (table 6) to provide efficient spectral coverage from 3000 to 10,000 \AA . The echelle spectrograph is used with CCDs to obtain spectra of stars as faint as $m_v \sim 15$ or even fainter, depending on the resolution and signal to noise required. As NOAO has an ongoing CCD evaluation program, new chips are occasionally available which may be useful for a particular application. A list of “standard” CCDs is given in table 8.

Overall throughput of the spectrograph and UV camera has been measured to be $\sim 1.3\%$ at 3900 \AA and $\sim 4.7\%$ at 5900 \AA . These values are probably also good estimates for the throughput when the long focus cameras are in use. With the UV camera, TI CCD and 58-63° echelle, spectral coverage is complete in the UV and blue spectral regions. Coverage is complete to $\sim 7000 \text{ \AA}$ with the 31-63° echelle and TI CCD. The long focus cameras require 2048 size CCDs to obtain complete spectral coverage out to 9000 \AA , but at 4000 \AA a 1024 CCD will suffice. See §2.11 for examples of calculations of spectral resolution and coverage.

The instrument is operated almost completely remotely from the console room through a computer-CAMAC system. The guider-rotator allows automatic guiding and rotation of the spectrograph to project the slit at any angle on the sky. An ICCD (Intensified CCD) acquisition TV is used for viewing the object on the slit as well as for finding guide stars.

2 Description of the Spectrograph

In this section a description of each element of the spectrograph is given, progressing through the light path. The optical diagrams in figure 1 may be consulted for the arrangement of these elements. The prospective user need not be intimidated by the apparent complexity of the echelle spectrograph, since the actual operation of the instrument is straightforward, and the instrument assistant and telescope operator will handle most of the setup and computer interaction.

2.1 Pre-slit Filter Wheel

The pre-slit filter wheel (figure 1) contains six 2” x 2” (50.8 x 50.8 mm) filters, used mainly for cross disperser order separation. Their use may be preferred to the post-slit filters as a collimator focus change may be required for the latter. Table 1 contains a list of these filters and figure 2 illustrates their transmission curves. A spare filter wheel is available for special filters or filters supplied by the observer.

2.2 Front Slit Viewer

Front slit viewing is available at all times and is used for acquisition of the object and guide stars. While an eyepiece is available for direct viewing, the usual mode is with an ICCD TV

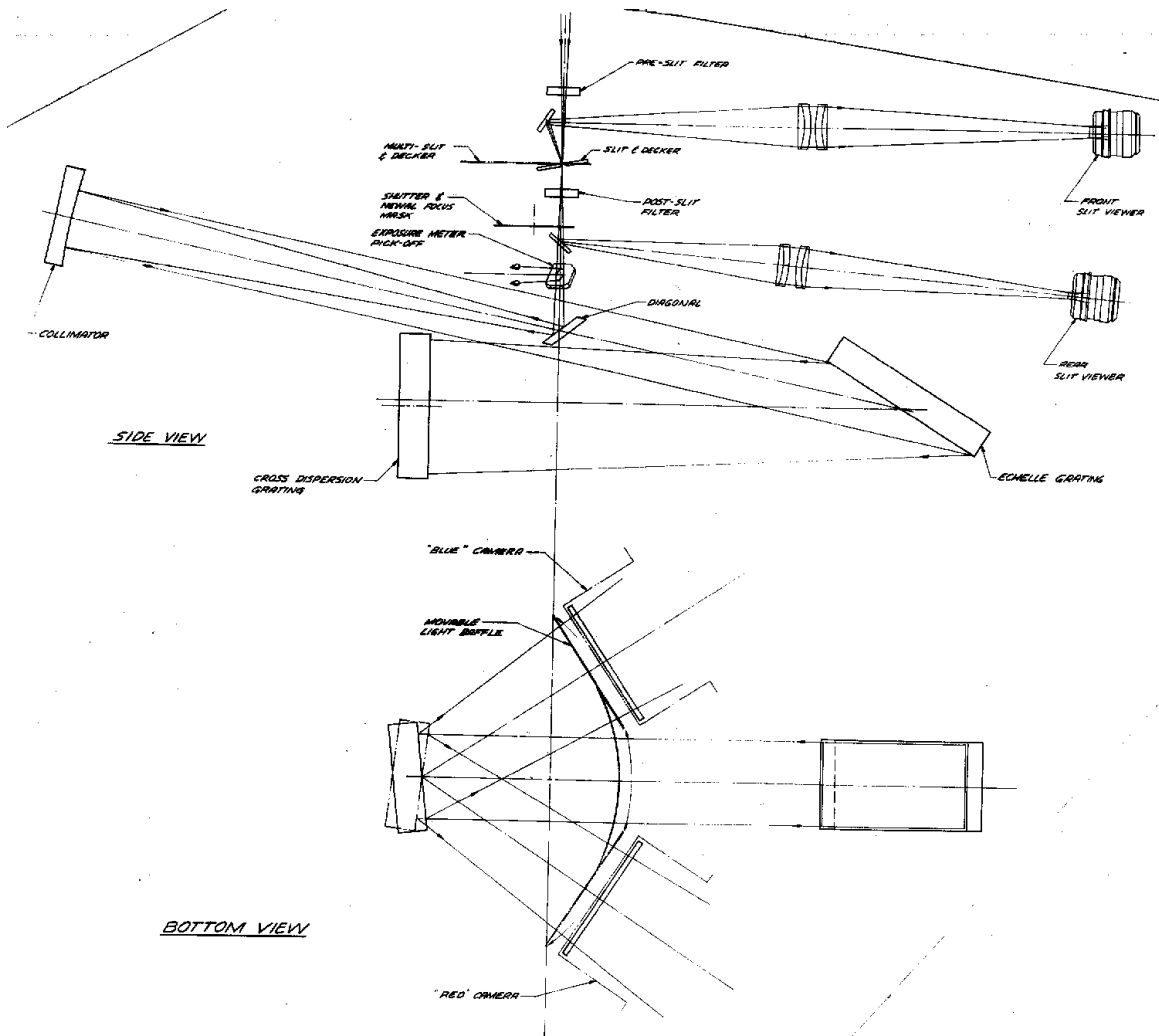


Figure 1: Side and bottom views of 4m echelle spectrograph.

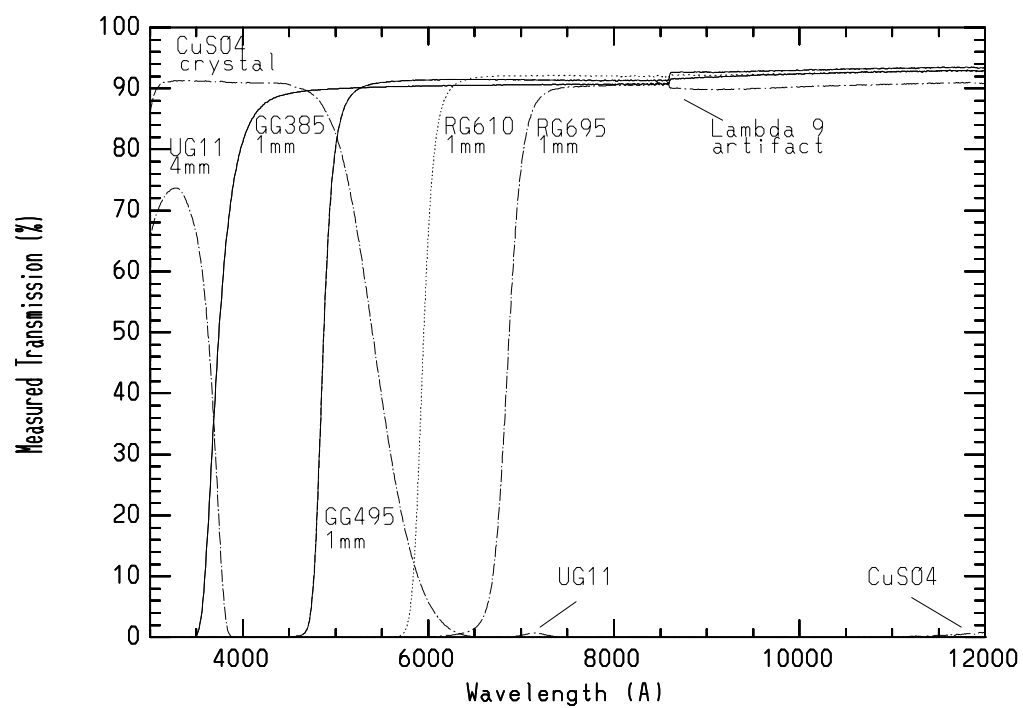


Figure 2: Filter transmission curves.

Pre-Slit and Post Slit Filters		
position	filter	thickness (mm)
pre-slit (2" x 2")		
1	N.D. - 2.5 mag	2
2	N.D. - 5.0 mag	2
3	GG-385	2
4	GG-495	2
5	RG-610	2
6	CuSO ₄	6
7	open	-
post-slit (1" x 1")		
1	N.D. - 2.5 mag	2
2	N.D. - 5.0 mag	2
3	GG-385	2
4	GG-495	2
5	RG-610	2
6	RG-695	2
7	optional*	-
8	open	-
*special 2" x 2" holder		

Table 1: Pre-slit and post-slit filters

monitored in the console room. This arrangement yields a 75 x 100 arc-sec field. Stars as faint as about $V = 19.5$ are visible on the TV with the leaky memory during dark time with 1" seeing.

2.3 Slit

The bi-parting slit consists of two polished and aluminized Tantung-G plates set at an 11 degree angle to allow preslit viewing (figure 1). Minimum closure is 12 μ , and 50 mm is the maximum opening. The slit is usually set by the computer to the desired width.

2.4 Decker

Two decker plates which slide just above the slit (figure 1) are available to control the slit length. Tables 2 and 3 list the stellar and comparison dimensions and their projected sizes on the detector. The maximum usable decker size will depend upon the wavelength, the echelle grating, and the amount of cross-dispersion. For the long focus cameras, figures 3 - 6 show plots of order separation vs. wavelength which may be used to select a suitable decker, given the dimensions in tables 2 and 3. The values from the graphs may be divided by 2.2

for the UV camera. The selection of a decker length may be determined by the need to do sky subtraction and the order separation. Decker number 1 is usually preferred for stellar observing since it has a larger selection of small openings.

2.5 Post-Slit Filter Wheel

There are seven post-slit filter positions (figure 1) and one open position. Table 1 contains a list of these 1" x 1" (25.4 x 25.4 mm) filters, and their transmission curves can be found in figure 2. All filters (except CuSO₄) are anti-reflection coated for maximum throughput. The focus change required is -10 collimator (encoder) steps per millimeter of filter thickness if the spectrograph is focused without a post-slit filter in the beam. Proper collimator focus is important to avoid astigmatism in the image.

2.6 Post-Slit Viewer

The post-slit viewer (figure 1) allows one to view from below the light coming through the slit. For this purpose a flat mirror is rotated into the beam manually or via computer. This viewer is useful for checking the light path for obstructions and for doing knife-edge focusing using the slit and a star. The pickoff mirror must be out of the beam when not in use.

There is normally no TV available on this viewer.

2.7 Shutter and Newell Mask

The four positions of this mechanism are

1. shutter closed
2. shutter open
3. top half of beam masked
4. bottom half of beam masked.

The shutter may be activated either by the CCD computer directly or the telescope computer running the echelle program depending upon switch settings on the instrument. The Newell mask shutter positions may be used to focus the collimator if desired, but must be done manually at the present time. The proper collimator setting will usually be set by the instrument assistant, leaving only the CCD to be focused. The collimator setting depends on which optics are installed, filters used, and the spectrograph alignment.

2.8 Exposure Meter and Exposure Meter Pickoff Mirror

This device is currently not functional.

Echelle Decker No. 1 (small set) Dimensions					
decker number	stellar length (mm)	projected decker size (mm)		arc-sec on sky ^c	comparison slot sep. (mm) – inner edges
		long focus camera ^a	UV camera ^b		
0	–	–	–	–	0.31
1	–	–	–	–	0.75 ^d
2	–	–	–	–	0.35
3	–	–	–	–	0.50
4	–	–	–	–	0.66
5	–	–	–	–	0.81
6	–	–	–	–	0.96
7	–	–	–	–	1.27
8	–	–	–	–	1.42
9	–	–	–	–	1.72
10	–	–	–	–	2.37
11	0.17	0.10	0.04	1.12	–
12	0.32	0.19	0.08	2.12	–
13	0.44	0.26	0.12	2.91	–
14	0.60	0.36	0.16	3.97	–
15	0.70	0.42	0.18	4.63	–
16	0.80	0.48	0.21	5.30	–
17	1.12	0.67	0.29	7.41	–
18	1.47	0.88	0.39	9.73	–
19	2.29	1.38	0.60	15.16	–
20	3.02	1.82	0.79	19.99	–
21	4.53	2.73	1.19	29.99	–
22	5.89	3.55	1.55	38.99	–

^ademagnification perpendicular to dispersion = 1.66
^bdemagnification perpendicular to dispersion = 3.8
^cscale at slit = 6.62 arc-sec mm⁻¹
^dspecial observing apertures, 0.38 mm wide

Table 2: Echelle decker no. 1

Echelle Decker No. 2 (large set) Dimensions					
decker number	stellar length (mm)	projected decker size (mm)		arc-sec on sky ^c	comparison slot sep. (mm) – inner edges
		long focus camera ^a	UV camera ^b		
0	base	–	–	–	–
1	0.55	0.33	0.14	3.6	–
2	1.06	0.64	0.28	7.0	–
3	1.55	0.93	0.41	10.2	–
4	2.07	1.25	0.54	13.7	–
5	2.60	1.56	0.68	17.2	–
6	3.07	1.85	0.81	20.3	–
7	4.13	2.49	1.09	27.4	–
8	6.17	3.72	1.62	40.8	–
9	8.19	4.93	2.16	54.2	–
10	10.25	6.17	2.70	67.8	–
11	12.27	7.39	3.23	81.2	–
12	14.29	8.61	3.76	94.6	–
13	16.33	9.84	4.30	108.1	–
14	18.37	11.07	4.83	121.6	–
15	20.38	12.28	5.36	134.9	–
16	–	–	–	–	0.15 (1 hole)
17	–	–	–	–	1.42
18	–	–	–	–	1.07
19	–	–	–	–	1.58
20	–	–	–	–	2.07
21	–	–	–	–	2.54
22	–	–	–	–	3.11
23	–	–	–	–	multi-hole
24	–	–	–	–	pointer
25	–	–	–	–	open

^ademagnification perpendicular to dispersion = 1.66
^bdemagnification perpendicular to dispersion = 3.8
^cscale at slit = 6.62 arc-sec mm⁻¹

Table 3: Echelle decker no. 2

2.9 Newtonian Diagonal Flat

The newtonian diagonal flat mirror reflects the diverging beam from the slit onto the collimator (figure 1). Two flats are available mounted on a common slide bar just below the slit. The “red” flat is silver coated with a sapphire overcoating and has excellent reflectivity ($\sim 98\%$) for wavelengths $>4000 \text{ \AA}$. The aluminized “blue” flat has good reflectivity from 3000 to 10,000 \AA and should be used below 4000 \AA with the blue collimator. Note that there may be a significant collimator focus position change when switching from one set of optics to the other.

2.10 Collimator

The f/8 collimators have a point-source beam diameter of 12.7 cm (5”) and a focal length of 101.7 cm. As with the newtonian flats, two collimators are available; one with silver and the other with aluminum coating. Each should be used with its corresponding flat and the proper focus setting to avoid astigmatism in the image. The optimum collimator positions may be significantly different for the two sets of optics, and KPNO personnel should be consulted for the proper settings. The current values are also listed next to the collimator readout on the spectrograph. The mechanical readout of collimator position on the spectrograph is one-half of the corresponding value at the computer terminal. To manually reset the position, be sure to release both the brake and the locking slide before turning the hand crank. Approach the desired setting from higher numbers. One mechanical readout unit = 50 μ . Increasing values move the collimator towards the newtonian mirror.

2.11 Echelle Gratings

Five echelle gratings are currently available; the individual specifications are given in table 4. The ruled area dimensions are 127 x 254 mm. Echelle gratings may be changed during the night, but angle settings should be determined prior to nighttime use to minimize loss of observing time.

Both the dispersion and the free spectral range (the wavelength difference between two wavelengths in adjacent orders at the same angle of diffraction) are set by the choice of echelle grating. These two properties, together with the amount of cross dispersion (limited to orders one through three of the cross dispersers), determine the spacing between orders. The 31.6 g mm^{-1} echelle grating, for example, will give complete spectral coverage (with the UV camera), but since the free spectral range is small, the orders are close together. While this may not be a problem for stellar objects, it could be serious for long slit spectroscopy. Wider spacing between orders can be obtained by using either the 58-63° or the 79-63° echelle. These echelle gratings may require some adjustment along the dispersion in order to center a particular wavelength on the detector. To manually reset the echelle grating, be sure to loosen both clamps (push up on the clamp handles) before turning the tilt knob. Approach the desired setting from higher numbers. Pull down on the clamp handles to clamp the grating motion. The echelle grating can also be set by the computer (§3). Tables 4 and 5 will be of use in adjusting the echelle grating.

Table 4 contains parameters for each echelle grating that can be used to determine the proper grating setting, dispersion and order separation for a given wavelength. For example, given the 79-63° echelle and a long focus camera, an observer wishes to know the above quantities for observing at H α . From table 4, the first order echelle blaze wavelength is given from which the order of interest can be determined:

$$m = \frac{(1^{st} \text{ order blaze } \lambda)}{\lambda} = \frac{224994 \text{ \AA}}{6563 \text{ \AA}} = 34.28$$

or H α would fall closest to the center of order 34.

The dispersion is given by

$$d = \frac{\lambda}{2 \tan \theta_B f} = \frac{6563 \text{ \AA}}{2(\tan 59.72)(590 \text{ mm})} = 3.25 \text{ \AA mm}^{-1}$$

where θ_B is the angle of the echelle blaze peak and f is the camera focal length (§2.13).

Since the blaze λ of order 34 is

$$\frac{224994 \text{ \AA}}{34} = 6617 \text{ \AA} \text{ (encoder = 1843)}$$

the echelle grating would have to be tilted

$$\frac{\frac{6617 \text{ \AA} - 6563 \text{ \AA}}{3.25 \text{ \AA mm}^{-1}}}{0.24 \text{ mm per encoder step}} = +69 \text{ encoder steps}$$

to center H α .

An estimation of the spectral coverage perpendicular to the echelle dispersion can be obtained given the amount of cross dispersion (table 6). With the T2KB CCD (49.2 x 49.2 mm) and 226-1 cross disperser the spectral range is

$$(70 \text{ \AA mm}^{-1})(49.2 \text{ mm}) = 3440 \text{ \AA}.$$

Note that this is independent of echelle grating.

The free spectral range at H α would be

$$F = \frac{\lambda}{m} = \frac{6563 \text{ \AA}}{34} = 193 \text{ \AA}$$

which implies that the order separation would be

$$\frac{193 \text{ \AA}}{70 \text{ \AA mm}^{-1}} = 2.76 \text{ mm}.$$

Another way of determining the spectral coverage and arrangement of specific wavelengths covered in a CCD frame is by use of the Th-Ar maps and overlays kept at the 4-m telescope.

Echelle Gratings					
Parameter	Grating Designation				
	79-63°	58.5-37°	58.5-63°	31.6-63°	316-63°
grooves mm ⁻¹	79	58.5	58.5	31.6	316
blaze angle (°)	59.72	34.12	59.35	59.47	59.05
FSR* (Å @5000 Å)	109	123	77	44	436
blaze center:					
mechanical	4460	4740	4460	4456	4456
encoder	2843	4922	2843	2792	2775
recip. disp. (Å mm ⁻¹ @5000 Å):					
UV camera	5.7	14.5	5.8	5.8	5.8
long focus	2.47	6.25	2.51	2.50	2.5
demag. along dispersion:					
UV camera	6.2	4.1	6.2	6.2	6.2
long focus	2.67	1.77	2.67	2.67	2.67
first order blaze λ (Å)	224,994	195,030	303,500	557,855	56,331
*Free Spectral Range: The wavelength difference between two wavelengths in adjacent orders at the same angle of diffraction.					

Table 4: Echelle Gratings

Echelle Grating Adjustment
long focus camera: 1 mech. = 7.5 encoder = 2.1 mm on CCD 1 encoder = 0.24 mm on CCD
UV camera: 1 mech. = 7.5 encoder = 0.90 mm on CCD 1 encoder = 0.10 mm on CCD
+ encoder steps moves toward shorter λ

Table 5: Echelle Grating Adjustment

2.12 Cross Disperser Gratings

The four cross dispersing gratings currently available are 165 x 220 mm with a slightly smaller ruled area. Here again changing cross dispersers is possible during the night, but should be minimized to prevent loss of observing time due to setup and alignment.

Table 6 contains grating specifications, while figure 7 shows the cross disperser efficiencies vs. wavelength. Figures 3 - 6 may be consulted for more detailed order separation data (plot of order separation vs. wavelength), or order separations may be calculated as in §2.11.

In addition to the cross disperser gratings, a silver coated flat is available which can be used in conjunction with a narrow band order separation filter to provide high resolution spectra of a single order for maximum spatial coverage.

Cross Disperser Gratings					
grating number	KPNO ruling number	grooves mm ⁻¹	first order blaze (Å)	first order disp. (Å mm ⁻¹)	
				long focus	UV camera
226-1	KPC-21	226	6700	70	160
226-2	KPC-4	226	9000	70	160
150-1	KPC-19	150	11,000	105	240
100-1	KPC-6	100	6300	162	371
Ag flat	—	—	4000 – 11,000	—	—

Table 6: Cross Disperser Gratings

For gratings 226-1,2 the encoder settings required to center a particular order of the echelle grating at the camera focus are given in figure 8. The cross disperser may be set by hand or by computer. To manually set the cross disperser, loosen the brake under the cross disperser housing (flip the lever ~ 180 away from the cross disperser access door) before turning the hand crank. Table 7 contains grating settings for loading, flipping, and zero order of the cross dispersers.

Cross Disperser Settings				
	left port (blue)		right port (red)	
	mech.	enc.	mech.	enc.
load	5400	859	5400	859
flip	1300	8912	1300	8912
0'th	2650	6259	3590	4415

Table 7: Cross Disperser Settings

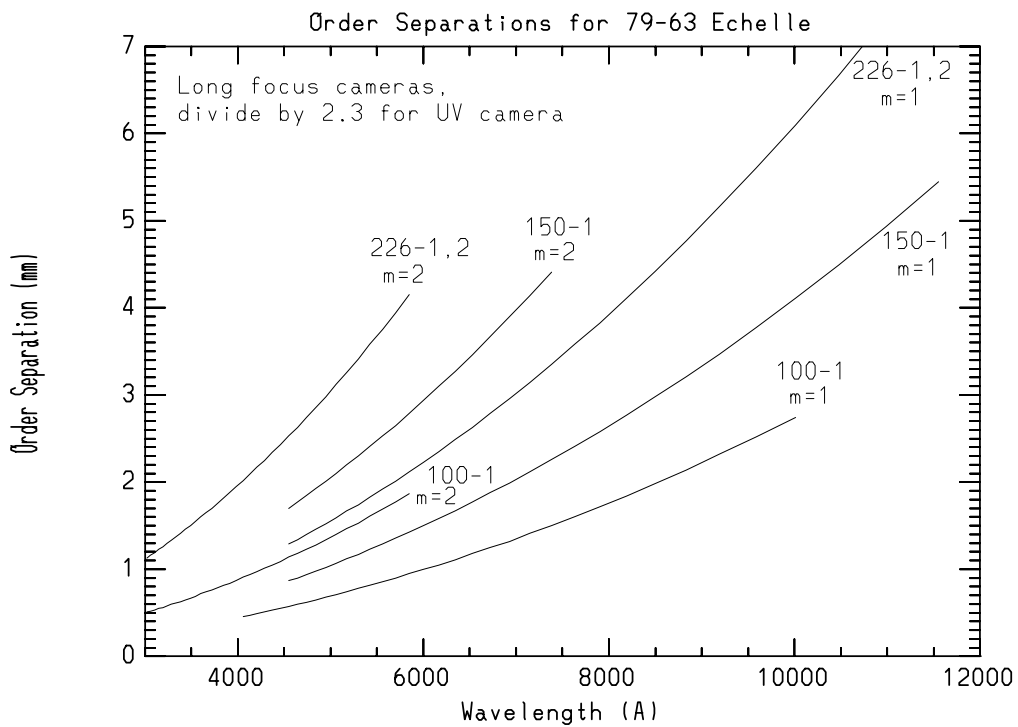


Figure 3: Order separations for 79-63 echelle and long focus cameras.

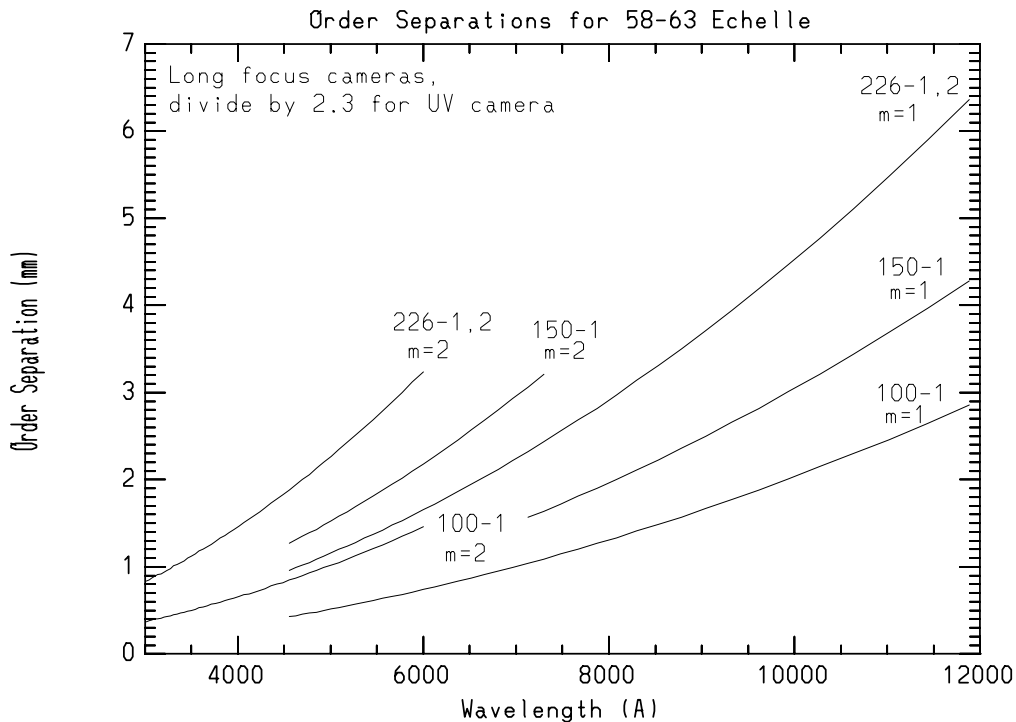


Figure 4: Order separations for 58-63 echelle and long focus cameras.

2.13 Long Focus Cameras

Two long focal length (590 mm, $f/2.5$) cameras, optimized for different wavelength regions are available for use on the echelle spectrograph. Both are folded Schmidts of essentially identical design, except for the correcting plates and optical coatings. The blue camera correcting plate is made of fused silica, while the red camera correcting plate is made of barium crown glass. The blue camera can be mounted only on the left camera port and the red camera only on the right port. The camera port baffle must be rotated into the proper position to block stray light from the camera which is **not in use**.

The orientation of the spectrum at the camera focus differs for the two camera ports. In both cases the echelle orders are nearly vertical with wavelength increasing upward. At the left camera port (blue camera), longer wavelength orders are to the left, while at the right camera port (red camera), longer wavelengths are to the right. At both ports, order separation increases with wavelength.

Only two cameras may be installed on the spectrograph at any one time; thus, either both of the long focus cameras or one of the long focus cameras and the UV camera (§3.15) may be mounted. Please consult your staff contact to determine the appropriate camera for your program. A further complication often arises due to more than one user scheduled successively

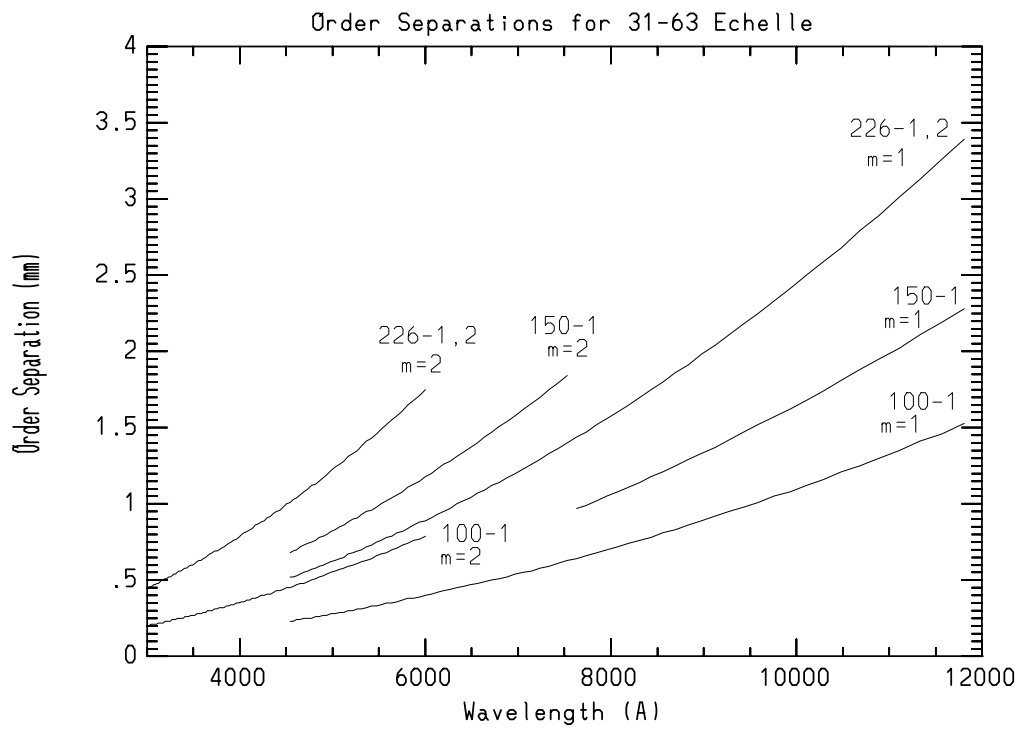


Figure 5: Order separations for 31-63 echelle and long focus cameras.

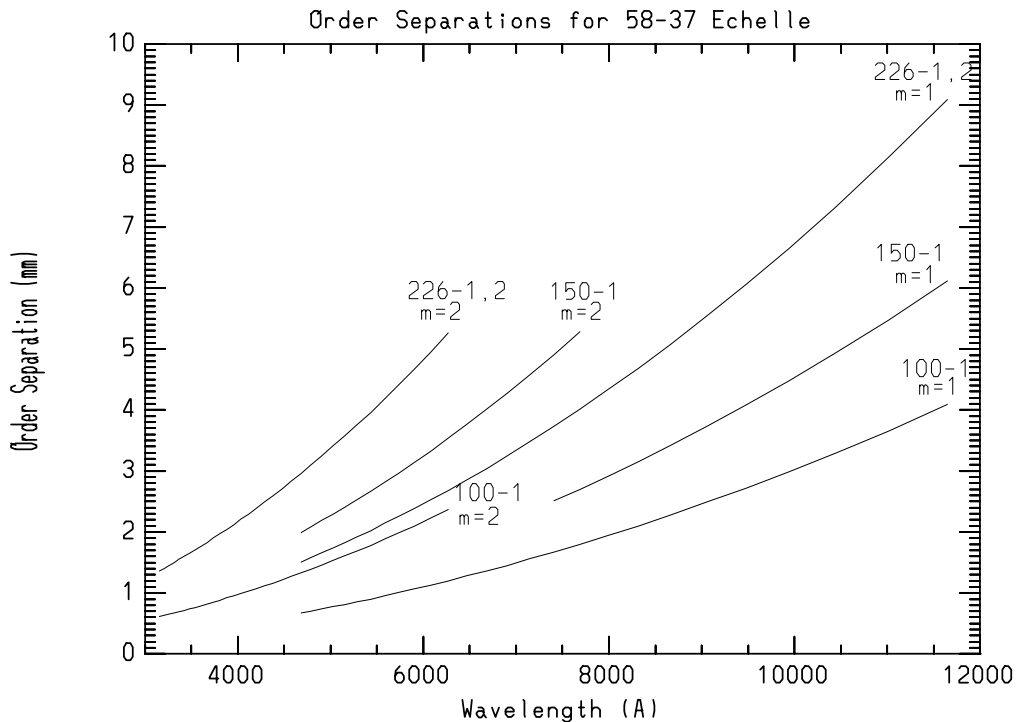


Figure 6: Order separations for 58-37 echelle and long focus cameras.

on the instrument during the time it is mounted on the telescope. Thus, compromises in the available cameras may be necessary. Final decisions in this regard will be made by Kitt Peak personnel after discussion with the observers. Observers who must use a particular long focus camera or the UV camera should state their needs clearly in the observing time request to allow compatible instrument scheduling.

2.14 UV Camera

The UV camera consists of a 267 mm focal length catadioptric objective lens, consisting of highest purity synthetic fused silica. The focal length yields plate scales and reciprocal dispersions approximately 2.2 times those of the long focus cameras.

3 Echelle Spectrograph Software

The spectrograph motors for setting gratings, filters, slit width, etc., can be operated from the console room through a GUI (Graphical User Interface). This OpenWindows interface consists of several windows which group similar functions together and also one general window for most of the spectrograph controls. Specific windows include grating and comparison windows.

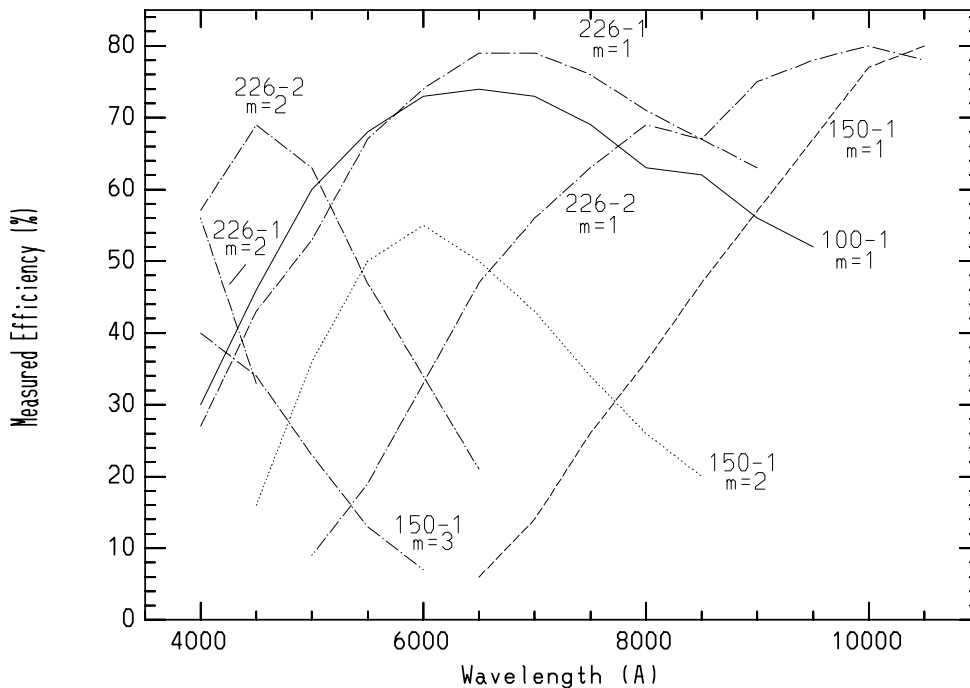


Figure 7: 4m echelle cross disperser efficiencies.

Motors are set by clicking the mouse on appropriate buttons and entering parameters such as wavelengths on the indicated lines. Since the setup of the spectrograph is done on the first day of a run by the instrument support person, a lengthy discussion of the control software will not be made. If the observer has a need to run the comparison lamps during the day, a quick demonstration can be made.

4 Direct CCDs on the Echelle Spectrograph

KPNO universal dewars can be mounted on either red or blue long focus cameras or the UV fast camera. The dispersions available from the long focus cameras are identical, but the blue camera is generally used for spectroscopy below 4000 Å. It is usually not possible to switch the dewar from one camera to the other during an observer's run.

5 CCD Characteristics and Spectrograph Performance

In theory any of the Universal dewars could be mounted on the echelle cameras, but in practice T2KB is generally used due to its large format, high quantum efficiency, and low readout noise.

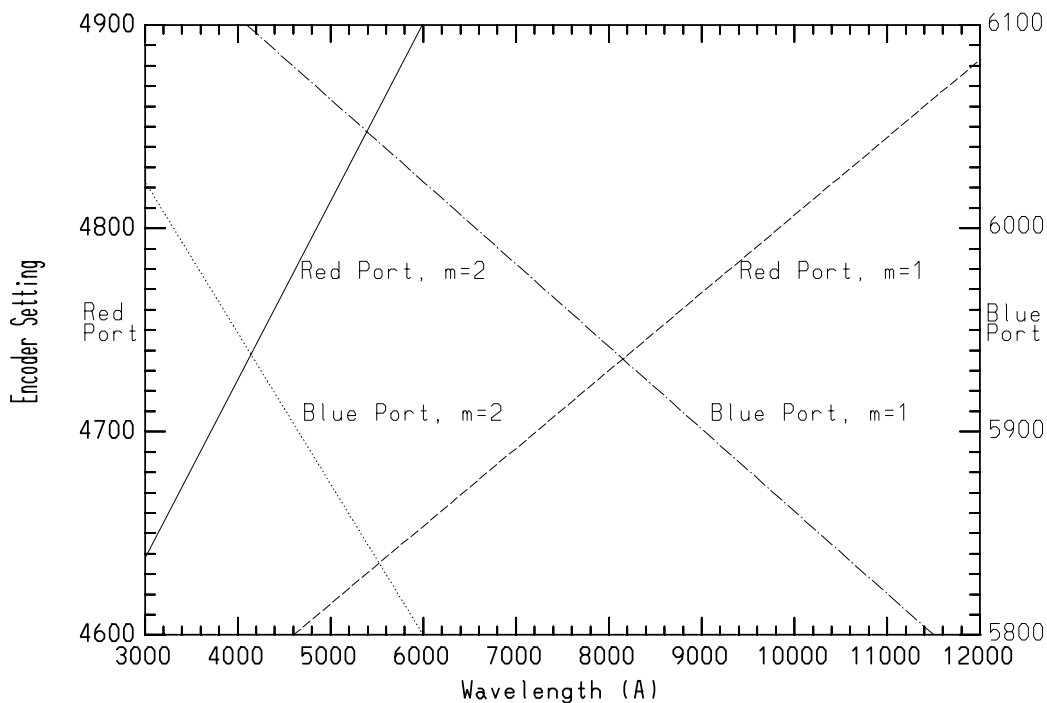


Figure 8: Cross disperser settings vs. wavelength for gratings 226-1,2.

If a need exists for small pixels, TI5 could be requested, and a slit width narrow enough to realize the higher resolution would be needed. The operating characteristics of these devices are given in table 8 and a graph of quantum efficiency vs. wavelength is shown in figure 9. As new CCD evaluation is ongoing at NOAO, prospective users may want to inquire about the newest devices available.

The CCD can be operated either with or without on-chip summation of pixels, in either the row or the column direction (or both), as appropriate to the requirements of the scientific program. The readout noise per summed pixel is approximately the same as that of one pixel even though the charges from several pixels per resolution element are added together.

Table 9 provides approximate values for limiting magnitude, resolution, signal-to-noise, and spectral coverage with the echelle-CCD system. Since these quantities are wavelength dependent, the values given are only typical. The following values assume the use of the 31.6 g mm^{-1} echelle grating, a 226 g mm^{-1} cross disperser, a slit width yielding 2 pixel resolution, 1.5 arc-second seeing, and on-chip summation in the direction perpendicular to the dispersion only ($15 \mu \times 30 \mu$ pixels for TI). More specific information for a particular spectral region may be calculated as in §2.11.

The TI CCD is usually aligned with orders along columns which allows placement of orders between the few bad columns on each chip. For some applications, the orders may be aligned

CCD Characteristics			
Parameter	T15	T1KA	T2KB
rows x cols	800 x 800	1024 x 1024	2048 x 2048
pixel size (mm)	0.015	0.024	0.024
dimensions (mm)	12.0 x 12.0	24.6 x 24.6	49.2 x 49.2
gain (e^- /adu)	4.3	1.7*	2.0*
readout noise (e^- rms)	8.0**	4.5	4.5
linearity $<0.05\%$ (e^-)	36,000	250,000	220,000
dark current (e^- /hr/pix)	<4	4	<4.0
radiation event rate/hr	low	650	2700

*default value; adjustable
**without preflash

Table 8: CCD Characteristics

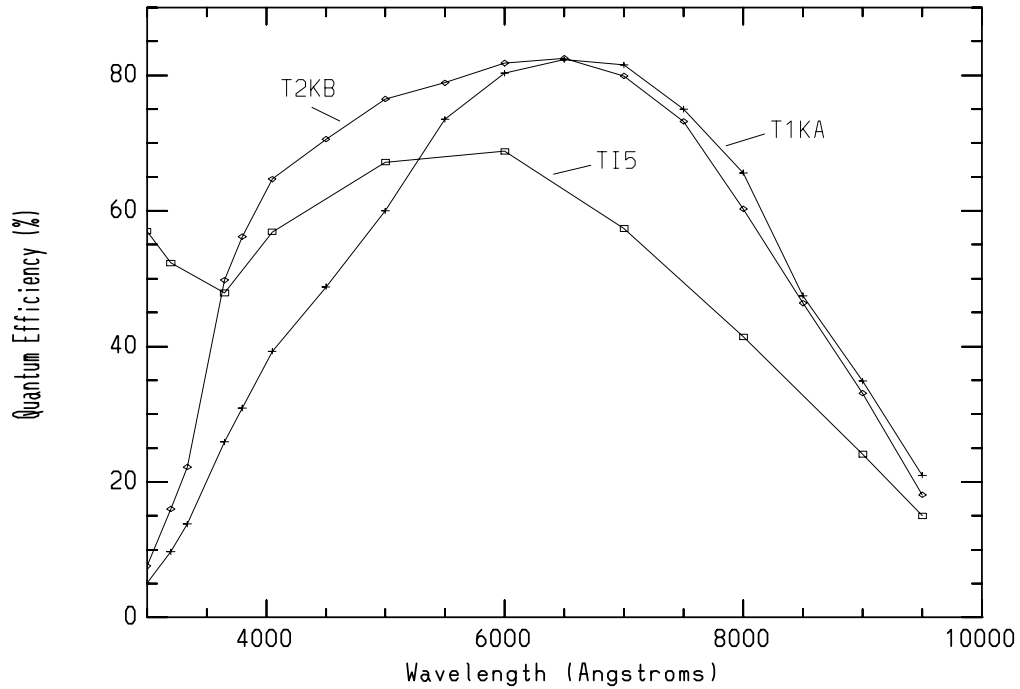


Figure 9: CCD quantum efficiencies.

Echelle-CCD Spectrograph Performance				
	T15		T2KB	
	blue (4000 Å)	red (6000 Å)	blue (4000 Å)	red (6000 Å)
resolution (Å) (for 2 pixels)				
long focus	0.06	0.09	0.10	0.14
UV camera	0.18	0.20	0.29	0.32
spectral coverage* (Å)				
long focus:	24 x 420	36 x 840	61 x 1075	92 x 2150
UV camera:	53 x 960	80 x 1920	136 x 2458	205 x 4915
limiting mag. in one hour at S/N=20/1				
long focus:	13.0	14.0	14.0	14.5
UV camera:	14.0	15.0	14.5	15.5
*along echelle dispersion x cross dispersion				

Table 9: Echelle-CCD Spectrograph Performance

along the rows of the CCD, or spectral lines may be oriented parallel to rows or columns.

5.1 Dewar Design and Maintenance

The CCDs are mounted in KPNO universal dewars. The design of these dewars is such that they can be used in any position (up, down, or side-looking). On the echelle spectrograph, the dewar is used in a side-looking position. Approximate LN2 hold time is 12 hours, but in some telescope orientations a portion of the LN2 may spill out causing an earlier warming of the dewar. The dewar temperature shown on the telescope control panel or given by the command **ccdinfo** should be monitored for any rise in temperature, and the dewar refilled if necessary. The mountain technical assistants and telescope operators will normally fill the dewar in the morning, evening and during the night if necessary. It is important to note that filling the dewar with LN2 may cause shifts in the pixel locations as large as two pixels. For this reason, it is important that the dewar be filled at least an hour before observing in the evening before initial calibrations are done. Calibrations should also be obtained after the dewar is filled during the night, should refilling be necessary.

5.2 Alignment and Focusing of CCD Dewar

The steps involved in preparing the echelle-CCD system for observing are:

1. Selection of wavelength region and resolution.

2. Selection of gratings and camera.
3. Gratings/wavelength adjustment.
4. Rotation of dewar to align columns (rows) parallel to spectra (or slit).
5. Focusing of dewar to bring surface of CCD chip coincident with camera focus.

This procedure is not necessarily a one pass operation; rough focus may have to be achieved before rotational alignment or vice versa. The wavelength centering may have to be done as a final step, but it should be kept in mind that the rotational alignment varies from order to order. Thus when aligning orders parallel to rows or columns, one needs to be fairly well centered on the desired wavelength region before doing the final rotational alignment. Alignment of the slit parallel to rows or columns will not be affected by wavelength adjustments.

1. Selection of Wavelength Region and Resolution. The needs of the science to be done tempered by the faintness of the objects determines the wavelength and resolution selection. Another factor is wavelength coverage. These decisions should be made at proposal time.

1. Selection of Gratings and Camera. These decisions are driven by item 1. Table 4 may be of use to help determine the most appropriate optics. Prospective users are also encouraged to consult KPNO staff. These decisions should also be made at proposal time.

3. Gratings/Wavelength Adjustment. Approximate encoder values for setting the gratings versus wavelength may be found in table 4 and figure 8. Spectra of the day sky in conjunction with a solar atlas may also be useful for wavelength positioning, especially in the far red where the Th-Ar is not as useful.

4. Rotational Alignment of the Dewar. If sky subtraction is not anticipated, the orders can be aligned parallel to the chip columns (or rows). This alignment will not be constant with order number due to the effect of approximately constant cross dispersion on the more rapid variation of dispersion between successive echelle orders.

The rotational alignment is determined by obtaining quartz lamp spectra and **imploting** one end of the spectrum, expanding around a few orders, and overplotting the other end of the spectrum. The cursor can be used to measure the profile positions (use the **C** key). On the long focus camera CCD mount, the four dewar rotation clamp screws must be loosened before adjustments are made. With the UV camera, the four small rotation lock screws on the front collar must be loosened to allow rotation. Coarse rotations are made by loosening the large, knurled clamp on the back of the long focus mounting bracket, or the 3 screws on the back of the UV camera mount, and rotating the dewar using the gold electronics box for leverage. (**Do not exert large torques on this box!**) Assuming the orders are parallel to columns (vertical), and if the upper end of the spectrum is shifted positively with respect to the lower end, then the following directions of motion apply:

- TI5 – counter-clockwise 0.18 mm/pixel
- T1KA – clockwise 0.13 mm/pixel
- T2KA,B – clockwise 0.065 mm/pixel

When the orders are parallel to rows, the directions are opposite those given above. If sky subtraction is important, the CCD should be rotated so that comparison lines are parallel to rows or columns to insure the same wavelength for the telluric features along the whole entrance aperture. In this case, a long slit is used (use long decker) and cuts are made across each end of a comparison line to determine the rotational misalignment as above. The correction factor will have to be scaled to the full chip format.

5. Focusing the CCD Dewar. 1. Long focus camera. Since the focal plane of the camera is fixed with the collimator at its proper position, the dewar must be adjusted so that the surface of the CCD chip coincides with the camera focal plane.

With the the rail micrometer set at about 5.00 mm, the dewar mounting bracket should be clamped at its nominal position which has the dewar mounting surface at 45.6 mm from the front of the camera. Now with the lower clamp bolt nuts backed off and the focus rail clamp released, successive spectra of the Th-Ar lamp can be obtained while decreasing the micrometer position by 0.25 mm until a rough focus is achieved. The final focusing should be done using smaller micrometer decrements of 0.05 or 0.10 mm. A FWHM of about 1.2 - 2.0 pixels should be obtained using a narrow slit and the TI CCD. Finally the lower clamp bolt nuts should be brought up firmly against each side of the mounting bracket, using care not to tighten one nut more than the other. The focus rail clamp is also now applied.

2. UV camera. In this case the dewar is fixed and the camera itself is moved in or out with respect to the CCD. This is accomplished by turning the large castellated nut on the front of the camera. A pair of handle-mounted rods are kept in the UV camera storage box to help in rotating the focus nut. These rods are inserted into the holes in the nut for ease in rotation. If the spacing between the focus nut and the camera body has been set to the nominal value of 1.312 inch (TI CCD), the focus should be within a few thousandths. The change in focus between each raised section of the focus nut is 0.025 inch.

The UV camera may also be focused with the transducer attached to the camera as a method of reading out the focus position and setting it initially. With the Fluke meter, read and set the camera focus focus to the values given below making the final setting towards more positive volts. A typical focus interval might be 0.1 volt and the camera motion is 0.311 mm per volt. The total transducer range is +14 to -14 volts with +14 volts bringing the camera closest to the dewar window.

5.3 Observing with the Echelle-CCD System

Before you arrive at Kitt Peak, you should discuss with your staff contact the instrumental requirements of your scientific program, and choose the gratings that will best satisfy the

CCD	TRANSDUCER VOLTAGE
TI5	-8.0v
T1KA	-14.4v
T2KA	-5.5v
T2KB	-3.5v

Table 10: Transducer Focus Voltages for UV Camera

needs of the program. Your instrument assistant will install the appropriate gratings in the spectrograph, and align and focus the dewar for the wavelength region you have requested. The procedures to align and focus the CCD are described in the previous section of this manual.

Once the CCD has been aligned and focused, the required calibration exposures should be made. These calibration data include zero (bias), comparison, flat field, and, possibly, dark frames. An initial set of calibrations can be made just before dark, and additional images secured at convenient times during the night. Be sure to repeat all of the calibrations each night as small changes of dewar position may occur when the dewar is filled with LN2.

Before any data is obtained the observer must decide whether on-chip summation of pixels will be used. If the spectra are several pixels wide, or the full resolution of the instrument is not needed, the charge from adjacent pixels on the CCD may be added together during the read-out operation. Especially for low-light level observations, on-chip summation improves the final signal-to-noise of the data. The counts from several pixels are added, but the read-out noise is equivalent to only one pixel. On-chip summation will increase the dark current per equivalent pixel, but for most applications the dark current will still be less than 5 ADUs per hour.

The TI CCDs exhibit some charge transfer defect which evidence as assymetric wings on comparison lines. This may not be a problem for stellar spectra where the lines are measured from a continuum of hundreds of ADUs or more, but for weak spectra or faint emission lines, the charge can become seriously smeared. Performance can be somewhat improved by “preflashing” the CCD up to a level of ~ 20 ADUs. This can be done using the LED lights in the dewar shutter and setting the preflash time in the **detpars** task (§6.3). When the UV camera is in use, the dewar shutter is removed but several LEDs are mounted between the dewar and UV camera for preflashing. Use of this technique can reduce distortion of line profiles and bring out features otherwise lost due to poor charge transfer.

Comments are given below on the various types of pictures:

zeros A DC offset is added to the overall signal from the CCD to insure no negative data. This “pedestal” level (a few hundred ADUs), formerly known as “bias” has no particular significance other than it must be very stable. Obtain 20 - 30 per night. Can be spaced throughout the night or split between beginning and end of night. Zero exposures are important for the TI CCDs where preflash is generally used, but may not be necessary

for some of the TEK CCDs where the bias level is very uniform. In this case one could use the overscan or the region on each side of the spectrum to subtract the bias level.

darks Dark integrations are probably unnecessary for most applications. You may want to obtain a couple 10 or 20 minute darks just to check on dark current and look for any hot pixels. The dark current is sometimes high if the chip has been exposed to too much light, or if power has been interrupted to a cold chip. The spectrum may be moved to avoid any bad regions on the chip.

flats Obtain a total of at least 10 times the number of ADU's compared to the count rate of your most intense spectrum. For example if your spectrum has an intensity of 5000 ADUs, obtain at least 10 FLATS (preferable more) with 5000 ADUs each. To avoid non-linearities with TI CCDs, no spectrum (OBJECT or FLAT) should exceed 8000 ADUs. On-chip summing will extend these limits somewhat, but caution is advised. Values for other CCDs may be found in table 8. These exposures should be obtained at the beginning of the night so that reductions can proceed as the data is obtained. Additional calibrations can be obtained during the night if the gratings are moved or the dewar refilled. For flat field exposures, the same decker that is used for stellar exposures may be used as long as it is wider than the stellar image.

comps Obtain thorium argon exposures as needed for your scientific program. The instrument does suffer from some flexure, so if accurate wavelength calibration is required, comparison spectra must be taken while the telescope is pointed at the object. If you aren't interested in a careful wavelength calibration, comparison pictures can be skipped entirely. They are useful however, for monitoring the spectrograph resolution and applying a wavelength scale during subsequent reductions.

observe This is the command for obtaining spectra of astronomical sources. The same decker used for FLATS may be used with the object kept centered in it with the guider.

Observers are encouraged to use Exabyte or DAT tapes to record raw and reduced data. There is no one-half inch tape drive available at the 4 m anymore. An automatic data archiving system is functioning to record all images obtained. This system is intended for long term storage and not as a readily accessible backup medium. Observers are therefore encouraged to make two copies of their raw data or at least ftp a set to their home computer. Tapes should be labeled "computer grade" or "data grade" as many problems have been experienced with tapes of lower quality. Tapes may also be purchased on the mountain or downtown.

Subsequent data reduction will be much easier if the logsheets are filled out carefully. Please leave the originals in the notebook; copies can be made in the console room to take home.

5.4 Data Reductions

During the night while observing, observers may do as much of the data reductions as desired. This will be especially useful when more than one observer is present, as there are two computer terminals. This can reduce considerably the effort needed in subsequent reductions downtown or at the observers home institution. At the very least, calibrations frames can be averaged, images bias subtracted and trimmed, and flat fielding done. Various manuals exist for descriptions of the steps involved, a few of which are listed here:

User's Guide to the CCDRED Package, by Francisco Valdes;
User's Guide to CCD Reductions with IRAF, by Philip Massey;
User's Guide to Reducing Slit Spectra with IRAF, by Massey, et al;
Guide to the Slit Spectra Reduction Task DOECSLIT, by Francisco Valdes;
User's Guide to Reducing Echelle Spectra With IRAF, by Daryl Willmarth and
Jeannette Barnes.

6 Computer Operation

6.1 Overview

In the fall of 1991, the long-standing FORTH systems were replaced with an IRAF based acquisition system (ICE - IRAF Control Environment) running on Sun workstations. This enables the observer immediate access to the many IRAF routines for data reduction and analysis. This section is not intended to be a detailed description of the ICE, but a concise summary and quick reference. For more details see *An Observers Guide to Taking CCD Data with ICE* by Massey et al., and the references listed therein.

6.2 Logging In, Initializing ICE, and Logging Out

The SPARC station currently running ICE at the 4-m is named khaki. The login name is "4meter" and the current password can be obtained from the instrument assistant or observing technician and is posted on the front of the terminal. After logging in, the windows system will be automatically started and IRAF loaded. CCD data acquisition commands should only be issued from the left (red) window. Khaki has two terminal screens side-by-side which automatically configured to act as one large screen. The display (ximtool) window appears in the right screen leaving the left screen clear for issuing CCD commands and analysing data.

It is good practice to initialize ICE to its default values and delete all existing files at the begining of an observing run. First log out of IRAF in all windows and then type **obsinit** in any window with the Unix prompt (%). Answer the questions as they appear and then log out of the workstation completely (see below) in order for the changes to take effect.

Exiting the workstation is done by first logging out of all IRAF windows. Now move the mouse to a blank area of the screen, holding down the right mouse button and select "exit" or "exit windows".

6.3 Parameter Sets

All IRAF tasks are controlled by parameter sets edited by typing

epar taskname

For example, to edit the task **wfits** type

epar wfits

and use the up and down arrows to position the cursor at different parameters. Merely type the desired parameter in followed by the **return** key to store the new value. Use **Ctrl-Z** or **Ctrl-D** (depending on the setup with **obsinit**) to save the new parameter set.

There are three parameter sets that control or modify the data taking process and should be modified to suit the observing needs. These parameter sets may be edited by just typing the name of the parameter set, unlike the discussion above.

detpars Controls the CCD readout parameters such as format, binning, and gain.

obspars Specifies image naming and other diverse header information.

telpars Most parameters supplied automatically by TCP/CCD link. If TCP computer is down, set *telname* to “test”; otherwise it should be “kp4m”.

There is one other parameter set, **instrpars**, which is currently not actively used by ICE; some of the parameters may be useful for later reductions.

6.4 Data Acquisition Tasks

observe Main observing task; prompts for image type, exposure time and title.

zeros Starts sequence of bias exposures; prompts for number.

objects Starts sequence of object exposures; prompts for number and exposure time.

flats Starts sequence of flat-field exposures; prompts for number and exposure time.

comps Starts sequence of comparison exposures; prompts for number and exposure time.

darks Starts sequence of dark exposures; prompts for number and exposure time.

test Start a test exposure that will overwrite any previous image named “test”.

mores Starts a sequence of **observes** identical to the previous one.

(p)ause Can be used to stop the integration clock and close the shutter.

(r)esume Used after **pause** to restart the integration clock and open the shutter.

(S)top Can be used after a **pause** to terminate an exposure at any time.

(A)bort Can be used after a **pause** to terminate an exposure with no data written to disk.

x Used after **pause** to change exposure time. Follow with **resume**.

t Used after **pause** to change title. Follow with **resume**.

6.5 Image Tasks

imcopy Copies an image, or subraster of an image, to another image.

imrename Renames an image.

imdelete Delete an image or images.

imheader List image headers.

hedit Edit the header parameters of an image.

hselect List specific items from the image headers.

imhist Plot a histogram of the pixel values in an image.

imstat Print statistics on an image.

implot Interactively plot columns and lines of an image.

splot Interactively plot lines or columns of an image with spectral analysis tools.

6.6 Tape Tasks

allocate Allocate a tape drive; e.g.: **allocate mta** or **allocate lapis!mta**.

deallocate Deallocates a tape drive.

wfits Write a FITS format image to tape or disk.

rfits Read a FITS format image from tape or disk.

mtexamine Examines a magnetic tape.

6.7 Miscellaneous Tasks

diskspace Check capacity of disks.

dir List files in current directory.

display Display an image in the IMTOOL window.

files Generate a list of files for taping or other reductions.

ccdinfo List all CCD parameters such as gain, format, binning, etc.

help On-line help documentation; e.g.: **help observe**.