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THE R.C. SPECTROGRAPH FOR THE MAYALL 4-METER TELESCOPE

--- INSTRUMENT REFERENCE MANUAL ---

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December 1, 1992

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1. INSTRUMENT OVERVIEW

The 4-Meter R.C. Spectrograph with UV Fast Camera and CCD in a Universal dewar offers an excellent combination for low to moderate resolution ($270 \leq R \leq 6000$) two-dimensional spectroscopy of astronomical sources. The most popular combination, using a Tektronix 2048x2048 chip [T2KB], offers good sensitivity from near the atmospheric cutoff to the 9500Å region. A CCD quantum efficiency of ≥60% occurs in the region 4000-8000Å. The Tek chips have 24μ square pixels and can cover the full slit length (5.2 arc-minutes) at a scale of ~0.69 arcsecs/pixel. Spectral resolutions of 1-15Å are available using a large selection of diffraction gratings. The CCD system operates under IRAF/ICE on a Sun Sparc 2 workstation.

With the T2KB chip, the system can obtain spectra of 18th. magnitude (V) stellar objects in an hour at R~430 (14Å) with a S/N~60 per pixel. The overall efficiency of the system, including the throughput of the atmosphere, telescope and spectrograph/detector, is 6-8% in the 5000-6000Å region. The Tek CCDs typically have rms read noise of 3-5 electrons and a full-well capacity of ~300,000 electrons for linearity ≤0.05%. The cosmic ray event rate is significant and it is suggested that long exposures be broken up into 30-60 minute segments to discriminate against these events.

Two operating modes are available: the normal long slit mode and a multi-slit configuration using special entrance masks. Potential users of the multi-slit mode should refer to *An Observer's Manual for the Cryogenic Camera* for detailed information. Multi-slits require considerably more advanced preparation than is required for the conventional long slit mode. Potential users are urged to talk with one of the staff contacts early.

Atmospheric dispersion compensation is available using the automated Risley prisms located in the Cassegrain instrument rotator (see Appendix IV).

Full data reduction capability using IRAF is available at the 4-meter using either of two SUN-Sparc workstations (UNIX).

2. OPTICAL DIAGRAM

FIG.1

3. THE 4-METER INSTRUMENT ROTATOR AND GUIDER

3.1. Introduction

The Rotator/Guider provides the interface between the telescope and the R.C. Spectrograph. These devices are multi-functional providing rotation for the spectrograph, guide probes for locating guide stars, calibration light sources and auxiliary optics for TV acquisition systems. A set of Risley prisms is available for atmospheric dispersion correction.

3.2. TV Acquisition Systems

The acquisition systems in use are modified RCA cameras with ISIT tubes (intensified silicon-intensified-target). The ISITs will be replaced by ICCD cameras in the near future. Two ISIT systems are normally employed, one for wide field (~4 arcminutes) acquisition and the other for slit viewing (~2.5 arcminutes) during observing. An integrating video memory, the "Leaky Memory" is available for acquisition of faint objects. Stellar objects of V~20 can be seen under good seeing conditions with 8-16 seconds of integration (or "leak") using the wide-field system. Refer to section 4.2 of this manual for more information.

3.3. Spectrograph Position Angle Rotation

The spectrograph and auto-guider are remotely rotatable from the console room. Due to the asymmetrical weight distribution of the spectrograph, there are some restrictions with zenith distance. The guidelines are:

1) For large rotations (>2˚), the telescope must be **within 30˚ of the zenith**.
2) For small rotations or "tweaking" (≤2˚), the telescope must be within 50˚ of the zenith.

Additionally, for safety reasons, no one is permitted in the Cass cage during rotation if the telescope is more than 3˚ from zenith. See the memo posted in the console room.

The position angle can be readout either in the cage or in the console room. One can read to the nearest half degree on the cage readout and to the nearest tenth of a degree using the status monitor (VDU) in the console room. *The Telescope Operators are responsible for the safety of the equipment and personnel when rotating remotely.*

3.4. Guide Star and Target Acquisition

The acquisition of guide stars can be done quickly by the Telescope Operator using a special program "gstar" on the SUN to search the *Space Telescope Guide Star Catalogue*. The observer generally need **not** be concerned about selecting and pre-measuring guide stars, unless one is working well away from the galactic plane or in dark-cloud regions.. Full capabilities exist to electronically transfer target coordinates to the telescope control computer from outside the Observatory. See *NOAO Newsletter*, No. 30, June 1992, page 14 for details. Send your coordinates to 'coords@noao.edu'.

3.5. Specifications - 4-Meter Automatic Guider Probes

1. Guide Probes - two exist, one for the north half of the field and one for the south half. The north probe is an image dissector tube while the south is an ILS TV camera.

2. Range of the Probes:

a) East/West direction or X, ±140mm from the optical axis
b) North/South direction or Y, 0 to 210mm from the optical axis
c) Sign convention: East and North are +
d) The origin (0.0,0.0) is near the optical axis or slit center
e) Stars must be ≥45mm off-axis to avoid vignetting the object with the probe

3. Guide Star Magnitude Range: $9 < B < 14.5$

4. Offsetting: Precision offsets (~0.1") can be made using the guider. Closed-loop routines requiring a guide star, **bota** or **boaa**, are available. An open-loop routine not requiring a guide star, **tota**, is also available. See the Appendices for details.

5. Telescope Scale: 6.624 arcseconds/mm (150 microns/arcsec)

6. Guide Probe Filters

Position	Filter
A	Blue - BG37 (1mm)
B	Red - OG590 (2mm)
C	Neutral Density (NG3,1mm), ~2.5 mags.
D	Clear (quartz plate, 1mm)

3.6. Calibration Light Sources

The calibration sources are located on the northeast side of the Instrument Rotator and are controlled via the telescope control program. The main mirror in the Instrument Rotator must be in position 4 to allow the light to pass into the spectrograph. The unit consists of three individual sources coupled to an integrating sphere. Each source or port has an optional stepping motor controlled circular neutral density wheel and also a filter bolt for 2x2 inch filters. The ports are labeled A, B, and C. For CCD operation, port A is dedicated to the quartz lamp, port B is the Helium-Neon-Argon source and port C is a thorium-argon hollow-cathode lamp. The He-Ne-A is used for low-to-moderate resolution work and the Th-A hollow-cathode is useful for higher resolution work. A bright quartz lamp is also available for ports B or C. *Depending on the grating-wavelength combination needed, the neutral density wheel housing on ports B or C may have to be removed to increase (~5x) the brightness of the source*. In this mode only, the ND wheel will read a *fictitious ND=114 (fully attenuated)*. The software commands for controlling the calibration sources are found in later sections of this manual.

The table below summarizes the specifications of the source assembly.

Calibration Source Assembly

Port	Source	ND Wheel Range	Motor Step Range*
A	Quartz	0-4ND	0 to 76
B	He-Ne-A	0-2ND	0 to 114
C	Th-A Hollow Cathode	0-2ND	0 to 114

* Number of motor steps required by the software to cover the range of the ND wheels. Type **<n> cnd** to set.

4. The R.C. SPECTROGRAPH - SPECIFICATIONS

4.1. Introduction

The Ritchey-Chretien Spectrograph for the 4-meter telescope is the standard low resolution spectrograph in use at this telescope. It is a versatile instrument which has accommodated several detector systems over the years. Nearly all use at present is with CCDs. A particularly useful feature is the incorporation of an optical bench to the camera port on the spectrograph enabling a convenient and solid mounting location for detector systems.

Most of the components on the spectrograph can be moved by computer controlled stepping motors. A software package fully integrates control of the spectrograph with the telescope and guider (see Appendices I & II).

4.2. Front Slit Viewer

This optical system is designed for viewing the slit at all times using an RCA ISIT TV acquisition system. The optical design uses the light reflecting off the spectrograph slit for acquisition of the object and also allows monitoring during an exposure.

Three sets of transfer optics are available for differing magnifications of the slit. Normally either of the RCA lenses are used. The "Westinghouse" lens is almost never used. Observers doing long slit work may want the "RCA 1.5 to 1".

Lens Name	Use Field Lens Yes/No	TV Field Width (arcmin)	TV Screen Scale*	Notes
RCA 1.5 to 1	Yes	4.7	1.7"/mm	Best for wide field work
RCA 1 to 1	No	2.5	0.89"/mm	Good for "stellar" work
Westinghouse	No	1.5	0.54"/mm	Smallest field

* For a 166mm wide TV monitor

An integrating video memory, "the leaky memory" is available for acquisition of faint objects. Stellar objects of V~20 can be seen under excellent seeing conditions with 8 to 16 seconds of integration (or "leak"). Measured offsets are generally recommended for setting on stellar objects fainter than about V=18.5 under average seeing conditions.

4.3. Post-Slit Viewer

The post-slit viewer can be equipped with another ISIT TV camera allowing the observer to see what is coming through the slit. A motorized pick-off mirror gathers all of the light coming through the slit, and, therefore, prohibits its use during an observation. By manually inserting a special negative lens in front of the camera, knife-edge focusing of the telescope is possible. The post-slit camera is normally mounted only for multi-slit work.

4.4. Comparison Lens

This lens located immediately above the spectrograph slit is used in conjunction with the comparison calibration sources. The lens is necessary to produce a f/8 beam from the comparison sources and also significantly improves the uniformity of illumination.

Observers should be sure that this lens is NOT in position over the slit while focusing the telescope. The control software for operation of the spectrograph normally assures that this lens is IN position during calibration exposures and also, OUT of position, during object exposures.

Occasionally, dirt or other foreign matter may settle on this lens (due to the exposed environment) and cause "glitches" in the smoothness of the quartz calibration exposures. Since the dirt is on the lens, which is in place only for the calibration data, these "glitches" will *not* divide out of the object spectra. Please consult with your Instrument Assistant if any "glitches" become a problem.

4.5. Decker Dimensions

The decker is a movable mask located immediately above the slit to control slit length. Its dimensions are given in the following table. It is generally advantageous to reformat the chip to the size decker needed for the observations. Be sure to allow sufficient slit length for adequate sky subtraction. Consult the ICE/IRAF Software Manual for the reformatting parameters [in *detpars*].

No.	**Stellar Window**	
	Length	Length
	arcsecs	mm
1	12	1.85
2	24	3.71
3	49	7.42
4	98	14.86
5	205	30.99
Open	5.4	50.

4.6. Slit

The slit is bi-parting with a length of 50mm and a maximum width of 50mm. The front surface is aluminized and tilted for use with the front slit viewing system acquisition TV. Typical slit widths are 150-400 microns or 1 to ~2.5 arcsecs. The scale of the 4-meter telescope is **6.624 arcsecs per mm** (150 microns/arcsec). On the chip the spatial scale is 0.69 arcsecs/pixel for a 24-micron pixel TEK chip.

The slit width is readable via the encoder and spectrograph control software or via the mechanical Durant counter on the spectrograph itself. Each unit on the Durant counter is 20 microns. Note that the slit encoder has 15 bits and, consequently, can only be set to 32,767 microns via computer [for multi-slit programs]. Hand cranking is required to reach the full 50mm width.

Great care must be taken when setting the slit width, as damage can result if the mechanism accidentally attempts to set widths less than about 12 microns.

4.7. Spectral Resolution and Slit Width

Below is a conservative estimate of the trend of resolution or FWHM (full-width at half-maximum) versus slit width for the instrument using a TEK CCD. The spatial scale is **~0.69 arcsecs/pixel**. It should be pointed out that there is a general trend of slightly poorer focus as one goes from the center of the field to the edge. In the spatial direction, the trend is about a 20% degradation when going from center-to-edge along a spectral line (at field center). The diagram below is a best case example and, in practice, slightly poorer focus is experienced.

Figure 2

The usual procedure for slit width selection has been to match the resolution of the detector by dividing the actual slit width by the so-called demagnification factor, or the ratio of collimator-to-camera focal lengths. However, for spectrographs such as the RC spectrograph, this approximation is not always valid. For cases when the collimator-to-camera angle is greater than ~15°, the full expression for projected slit width should be used.

$$w = r\,(f_{cam}/f_{coll})\,W$$

Here w is the projected slit width, W the actual (physical) slit width, and r is the "grating anamorphic magnification". The factor r is a function of the grating tilt and collimator-camera angle, i.e.

$$r = \cos(t+\phi/2) \,/\, \cos(t-\phi/2)$$

where ϕ is the collimator-camera angle (46°) and t is the grating tilt. For the UV Fast Camera, the camera-to-collimator focal ratio is ~0.23 . At large grating inclinations the anamorphic demagnification factor becomes significant. In these cases the slit can be opened slightly wider without degrading the resolution. See F. Schweizer's article **PASP** *91*, No. 539, 149, 1979 for more information.

Be aware that at high grating inclinations (≤3500) the camera becomes over-filled resulting in throughput loss. This is a problem only with higher dispersion gratings.

Figure 3

4.8. Upper Filter Bolt - Order Separation Filters

The standard filter bolt contains the four filters listed below. These filters are 3.5-inches square.

Upper Filter Bolt		
Position	**Filter**	**Counter Setting**
1	Clear	734
2	GG-495, 3mm	567
3	GG-420, 3mm	381
4	RG-610, 3mm	197
5*	CuSO4†, 8mm	011

* Located at the handle end of the bolt.
† Mosaic filter, too small for multi-slit panoramic work.

Here is a complete list of the filters available for the upper bolt.

Filter:Thickness	Filter:Thickness
WG-345 1mm	BG-39 2mm
WG-360 2mm	OG-530 3mm
GG-375 1mm	OG-570 3mm
GG-385 3mm	*RG-610 3mm
*GG-420 3mm	RG-645 3mm
GG-455 3mm	RG-695 3mm
GG-475 3mm	RG-830 3mm
*GG-495 3mm	KG-2 2mm
*CuSO4 8mm†	KG-3 2mm
BG-38 2mm	

* Standard Filter Bolt

† Note: The CuSO4 filter is a crystal mosaic - very fragile. PLEASE DO NOT REMOVE IT FROM THE STANDARD FILTER BOLT. Also, due to its retangular shape, it will vignette the field and it should not be used for multi-slit panoramic work. *Observers and instrument support personnel should check that the proper filters or filter bolt is in the spectrograph. Don't make assumptions!*

Figure 4 - Copper Sulfate Crystal Filter Transmission

4.9. Lower Filter Bolt - Neutral Density Attenuators

The lower filter bolt contains Inconel on quartz substrate filters which are approximately neutral from ~3300 to 9000Å. The filters should be calibrated with a standard star for accurate spectrophotometry. These filters are 3.875-inches square.

Lower Filter Bolt		
Position	**Filter**	**Counter Setting**
1	Clear	735
2	0.0 mag.	567
3	2.5 mag.	381
4	5.0 mag.	197
5*	7.5 mag.	011

* Located at the handle end of the bolt.

4.10. Shutter

A "guillotine-type" shutter has been installed in the spectrograph replacing the original four-position spectrograph shutter. The new mechanism, operated via the CCD controller only, is fast and accurate. One second exposures are reproducible to within ±3%. The shutter motion produces equal exposure across all parts of the optical beam, unlike iris-type shutters.

4.11. Collimator Mirror

The mirror is an off-axis f/7.6 paraboloid with a focal length of 1161mm and a diameter of 241mm. The angle between the optical axis of the telescope and the center of the grating is 11°. The included angle from the collimator to the camera is 46°. The total focus travel is 38.1mm. The least significant digit on the mechanical readout equals 0.050 mm. The nominal center of travel is 500 on the readout. The auto-collimation position (without any filters in the beam) is 510 units. If the multi-slit assembly is used in place of the slit, the collimator position must be changed to ~290 for best focus. After a preliminary focus by moving the camera, a final spectrograph focus is made by adjusting the collimator position.

4.12. The UV Fast Camera

The UV Fast Camera is a catadioptric design done at NOAO by Jorge Simmons. The camera was fabricated early in 1986 and went into full service in May 1986. It has a thin meniscus corrector, a solid body with one internal surface acting as a secondary and a rear element attached to the main body followed by a single lens. There are six air-to-glass intervals and two aluminized surfaces. The back working distance is sufficient to reach into CCD dewars. The quartz material used is of the highest quality and the overall camera transmission is thought to be >85% for the region 0.3-1.1μ. The image quality is typically 25μ FWHM at the center of the field and ~35μ at the edge. The MTF is ~64% at 30 lp and ~30% at 50 lp, a noticeable improvement over the old Singer camera. The field vignetting is also noticeably improved over the Singer, only 5% at a field angle of 3 degrees. The focal length is 265mm, producing a slit reduction factor (demagnification) of ~4.4x. There is also sufficient clearance between the rear of the camera and the front of the CCD dewar for a chip preflashing assembly.

In order to achieve optimum focus, with the collimator near its auto-collimation position (510), the camera itself may have to be moved. If the collimator focus falls outside the range 425≤ collimator focus ≤575, the camera should be adjusted. *If collimator focus falls below 425, move the camera to HIGHER numbers on the engraved scale on the camera body*. Moving the camera longitudinally by ~.25mm will cause the collimator to move by ~100 units. This adjustment should only be attempted by someone intimately familiar with the instrument. The camera position is readout in volts from a linear transducer.

UV Fast Camera Focus Control

Turn Clockwise To Remove
Backlash and Make Final Setting
(toward more positive voltages)

Typical Focus Interval: 0.1 volts

0.012 inches / volt
0.311 mm / volt
CCW moves camera away from chip

In this camera design, a ray must make a triple-pass through many inches of quartz. Even though the optics are of the best grade quartz obtainable, scattering within the quartz may cause difficulties with flat-fielding for projects requiring very high signal-to-noise ratios.

4.13. Gratings and Grating Tilts

4.13.1. Grating Change Procedure and Policy

The current collection of twelve gratings represents a sizeable investment of capital and are a tremendous scientific resource. To protect this resource, we would like grating changes to be done either by your telescope operator, a technical assistant or your instrument assistant. Please let them take the responsibility as the gratings are quite heavy and difficult to handle. Grating changes at night can be done with only a loss of 10-15 minutes of observing time if tilts, filters, and focus are predetermined. Generally, however, it is most efficient to plan your observing program with grating changes taking place in the afternoon. *To protect the CCD from over-illumination, the curtain shutter over the UV Fast Camera should be closed for any grating change.*

4.13.2. Wavelength Coverage with Available Gratings

Wavelength Coverage With T2KB*					
Grating			Approximate Coverage in Å		
No.	l/mm	First Order λ Blaze (Å)	1st. Order	2nd. Order	3rd. Order
BL 250	158	4000	<8200†	--	--
BL 400	158	7000	8200	<4100†	--
KPC-10A	316	4000	<4100†	--	--
BL 181	316	7500	4100	<2000†	--
KPC-17B	527	5540	2500	--	--
BL 420	600	7500	2300	1150	--
KPC-007	632	5200	2100	--	--
KPC-22B	632	8500	2100	1050	--
BL 450	632	11,000	--	1050	700
KPC-18C	790	9500	1700	850	--
KPC-24	860	10,800	1600	800	--
BL 380	1200	9000	1100	550	--

* Since the edges of the chip are vignetted by the spectrograph camera, these coverages are based on approximately ~1500 pixels of spectrum.

† UV coverage limited by response of the chip, grating and atmosphere

4.13.3. Spectral Resolution with Available Gratings

Below is a table of spectral resolution for a slit width of 300μ or 2 arcseconds, assuming 2.5 pixels FWHM. Better resolution is available using smaller slit widths.

Spectral Resolution for the Available Gratings With TEK CCD					
Grating			Resolution - Å		
No.	l/mm	First Order λ Blaze (Å)	1st. Order	2nd. Order	3rd. Order
BL 250	158	4000	14.5	--	--
BL 400	158	7000	14.5	7.3	--
KPC-10A	316	4000	7.2	--	--
BL 181	316	7500	7.2	3.6	--
KPC-17B	527	5540	4.4	--	--
BL 420	600	7500	4.0	2.0	--
KPC-007	632	5200	3.7	--	--
KPC-22B	632	8500	3.7	1.9	--
BL 450	632	11,000	--	1.9	1.0
KPC-18C	790	9500	3.0	1.5	--
KPC-24	860	10,800	2.7	1.4	--
BL 380	1200	9000	2.0	1.0	--

GRATING DATA - R.C. SPECTROGRAPH + TEK-CCD				
Grating No.	BL250	BL400	KPC-10A	BL181
Lines/mm	158	158	316	316
Blaze Wavelength	4000Å	7000Å	4000Å	7500Å
Efficiency Chart No.	I	II	I	III
~Å/Pixel-First Order	5.52	5.52	2.75	2.78
Central Wavelength	**Grating Tilt (Order)**			
3000Å	6305	6155(II)	6153	5856(II)
3500Å	6281	6106(II)	6104	5758(II)
4000Å	6256	6056(II)	6055	5660(II)
4500Å	6232	6007(II)	6005	5561(II)
5000Å	6208	5958(II)	5956	--
5500Å	6183	6179	--	5907
6000Å	--	6155	--	5857
6500Å	--	6130	--	5808
7000Å	--	6106	--	5758
7500Å	--	6081	--	5709
8000Å	--	6056	--	5660
Zeroth Order	~6450	~6450	~6450	~6450
**********				
Grating No.	KPC-17B	BL420	KPC-007	KPC-22B
Lines/mm	527	600	632	632
Blaze Wavelength	5540Å	7500Å	5200Å	8500Å
Efficiency Chart No.	IV	IV	V	V
~Å/Pixel-First Order	1.68	1.52	1.39	1.44
Central Wavelength	**Approximate Grating Tilt (Order)**			
3500Å	--	5124(II)	5762	5053(II)
4000Å	5794	4934(II)	5664	4850(II)
4500Å	5712	4745(II)	5565	4649(II)
5000Å	5630	4555(II)	5467	--
5500Å	5548	5408	5369	5357
6000Å	5466	5313	5271	5256
6500Å	5384	5218	5173	5154
7000Å	5302	5123	--	5053
7500Å	--	5029	--	4951
8000Å	--	4934	--	4850
8500Å	--	4839	--	4748
9000Å	--	4745	--	4646
Zeroth Order	~6450	~6450	~6450	~6450

0

GRATING DATA - R.C. SPECTROGRAPH + TEK-CCD				
Grating No.	BL450	KPC-18C	KPC-24	BL380
Lines/mm	632	790	860	1200
Blaze Wavelength	11,000Å	9500Å	10,800Å	9000Å
Efficiency Chart No.	II	VI	III	VI
~Å/Pixel-First Order	1.39	1.14	1.07	0.74
Central Wavelength	**Approximate Grating Tilt(Order)**			
3500Å	4306(III)	--	3572(III)	3737(II)
4000Å	4000(III)	4479(II)	3151(III)	3292(II)
4500Å	3693(III)	4219(II)	3993(II)	2847(II)
5000Å	4408(II)	3959(II)	3712(II)	2401(II)
5500Å	4204(II)	3700(II)	3432(II)	4404
6000Å	4000(II)	3439(II)	3151(II)	4182
6500Å	3795(II)	3179(II)	2871(II)	3959
7000Å	3591(II)	4739	4554	3737
7500Å	3387(II)	4609	4413	3514
8000Å	4816	4479	4273	3292
8500Å	4718	4349	4133	3070
9000Å	4615	4219	3993	2848
Zeroth Order	~6450	~6450	~6450	~6450

Note: These gratings are also used with the Bench Spectrograph and Coude' Feed.

4.13.4. Grating Efficiencies

Below are charts showing the grating efficiencies. The rulings with KPC designations were ruled in the NOAO Gratings Lab [C engine] and the BL designations are Bausch & Lomb rulings. The measurements were made by Mr. Ian Gordon of the Kitt Peak (NOAO) Gratings Laboratory. All measurements are absolute efficiencies and were made at $\alpha+\beta=46^\circ$ corresponding to the collimator-to-camera included angle of the R.C. Spectrograph.

Figure 5

Figure 6

5. DETECTORS: CHARGE COUPLED DEVICES - CCDs

5.1. Introduction

The CCD system is controlled by a SUN Sparc 2 workstation [*khaki*] operating under the UNIX/IRAF environment. The CCD operates under the *IRAF Control Environment* or **ICE**. Documentation is available as a printed copy or on-line through anonymous-ftp (see Appendix). Khaki has a Sparc 2 processor with FPA and about 4GB of data space. Both a 9-track (6250/1600bpi) and a Exabyte tape drive are available. For most projects with the RC Spectrograph, the Tektronix (2048x2048) chip T2KB is used. A Texas Instrument chip (TI5) is available for programs requiring somewhat better sampling (15μ pixels vs. 24μ for the Tek chips) at the cost of less wavelength coverage, lower QE at almost all wavelengths, and poorer charge transfer.

5.2. The Tektronix Chip:

The chip normally assigned to the RC Spectrograph is T2KB. This is one of the best chips at the Observatory with ~4e^- rms readout noise, over 300,000 e^- full-well and excellent quantum efficiency. The default gain setting is 2.6e^-/ADU, although other values [see table below] may be used.

CCD NAME	T2KB (old t2k2)
CCD SN	1428BR03-01
PIXEL SIZE	24um
CHIP SIZE	2048 x 2048
TYPICAL DATA FORMAT	1600 x 500
BIAS OVERSCAN	32 columns
DIGITAL LIMITATION	32,767 ADU
BIAS LEVEL	~600 ADU
AMPLIFIER	D-amp
MICROCODE	T2KB
NOISE, e^- RMS	4.0
GAIN, e^-/ADU	13.9 10.5 7.0 4.2 2.6 1.4
GAIN, DETPARS #	1 2 3 4 5 6
PREFLASH e^-	none
LINEARITY, 0.05%, e^-	350,000
CONTROL TEMP. deg C	-90 (thermocouple)
DARK CURRENT, e^-/hr/pix	<4 (non-MPP)
DQE 900nm, %	33.1
DQE 800nm, %	60.3
DQE 700nm, %	79.9
DQE 600nm, %	81.8
DQE 500nm, %	76.5
DQE 405nm, %	64.9
DQE 365nm, %	49.8
DQE 320nm, %	16.0

5.3. CCD Quantum Efficiency

Figure 7

6. OBSERVING PROCEDURES

6.1. Introduction

Observing with this CCD spectrometer is straightforward. Generally a slit width of 1.5 to 2.5 arc seconds, or 230-380 microns, is typical for most observations. A decker can be selected to allow in enough sky adjacent to the object for a good sky determination. Excessively long slit lengths should probably be avoided, thus reducing the amount of scattered light in the system. The slit can be seen at all times during the exposure with the ISIT TV acquisition system on the front slit viewer. The telescope operator will locate and lock on a guide star.

6.2. Preliminary Setup Procedures

The focusing and setup of the instrument is done during the afternoon preceding the first night of observing. An Instrument Support person is normally present to help with focusing and rotation of the dewar, and calibrations.

One of the first decisions to be made is the orientation of the dewar with respect to the slit. With the dewar electronics box pointing east, dispersion goes along columns. With the electronics box upward, dispersion is along rows. Each orientation has its advantages and disadvantages. They are:

- **Dispersion along columns** (head electronics box east). Hot columns or dead columns will each intersect the projected slit at only one place spatially. Careful placement of your object on the slit can avoid these blemishes. Any charge transfer problems [TI chips] could put charge-tails on the lines and might affect the dispersion solution. Header: DISPAXIS = 2. CCD readout time will be somewhat longer since no rows can be skipped.
- **Dispersion along rows** (head electronics box up). Any hot or bad columns will chop-up the spectra at discrete wavelengths. You will *not* be able to avoid these blemishes by placement of your object on the slit. Any charge transfer problems will be in the spatial

direction so wavelengths will not be affected. This configuration is preferable for studies that seek to determine precise radial velocities or perform accurate sky subtraction of emission lines. *Most observers choose this orientation since the CCD readout time can be shortened by skipping rows*. Header: DISPAXIS=1

Focusing is done by moving the collimator to achieve the sharpest images on a He-Ne-A comparison spectrum. Dewar rotation is necessary to precisely align rows (or columns) with the slit. An instrument assistant will align the chip during the afternoon setup. Note that if a grating is rotationally "cocked" in its cell, it may not be possible to have *both* the projected slit image along a row and the dispersion exactly aligned along a column.

6.3. Calibration Procedures

After selecting the on-chip binning, if any, and data format in *detpars*, calibrations should be taken. Generally *the minimum set of calibration frames for long slit work consists of:*

- A good average bias or zero exposure
- A dome-flat and/or quartz lamp continuum exposure
- A short sky exposure
- A He-Ne-A or Th-A exposure

Generally a sequence of 20 biases is taken and then averaged. The *zerocombine* routine in the IRAF CCDRED package will combine and filter the sequence into a master bias or Zero image.

The quartz or ‘‘flat’’ exposure is used to map out the pixel-to-pixel sensitivity differences across the chip. This frame should have a maximum count of 15,000-25,000 ADU (analog-to-digital units) per pixel where photon noise is insignificant. The normalized differences between the actual intensity level in a given pixel and a polynomial fit to the spectrum represent the actual pixel-to-pixel sensitivity differences. This procedure corrects for the high frequency component in the system response but does not correct for the wavelength sensitivity differences across the chip, or for slit throughput variations. Some observers prefer to use the "Great White Spot" on the dome for flat-fielding, due to its better illumination uniformity along the slit. The over-head involved in obtaining "dome flats" at night is significant, however.

In order to correct for the throughput differences across the length of the slit, a short sky exposure (300-500 seconds) is needed to determine the ‘‘slit function". The sky is assumed to uniformly illuminate the slit, so by summing along individual columns, a profile of the relative throughput along the length of the slit can be determined. This is the so-called "slit function". Note that ‘‘dome flat’’ exposures are generally not needed if a short sky exposure has been taken. Some observers feel that dome flat exposures work better than sky exposures for the slit function (higher S/N).

At lower dispersions, the wavelength calibration of the data is determined from the He-Ne-A exposure. A map can be found in the Appendix. If you are working at high dispersion, consider using the line-rich thorium-argon source. See Daryl Willmarth’s **Th-A Atlas** for identifications of those lines. This calibration exposure is also used to map out the distortion in the data caused by the camera optics. The wavelength calibration exposures should generally be fairly strong, i.e. several thousands ADUs, in order to be able to use the weaker lines in the spectrum. The A-to-D converter saturates at 32,767ADU so exposures should stay several thousand ADUs below that level. A list of the wavelengths for several sources can be found in IRAF in the directory "linelists". The "noao/onedspec/identify" package is used to identify the lines and do a dispersion solution.

The quartz and He-Ne-A/Th-A exposures should be obtained at the time of the object integrations, preferably by ‘‘bracketing’’ the object exposures. The sky exposure can be obtained when convenient but on a dark night they will probably run longer than most observers are willing to take. A twilight sky exposure may prove useful and not require excessively long integration times. At least two ‘‘dark’’ frames (during supper) are useful to distinguish ‘‘hot

pixels" from cosmic ray events (‘‘hot pixels" will repeat).

If one is trying to do spectrophotometry, the wavelength response of the system must be determined by observing standard stars. Pick them from the ‘‘Standard Star Manual" in the dome if you are planning on reducing your data with IRAF. Refer to the Massey, Strobel, Barnes and Anderson paper (Ap.J. 328 , 315, 1988) for updated spectrophotometric standard stars. *To avoid problems with atmospheric dispersion, as large a slit width as is tolerable is advised, say 4-6*". The difficulty of spectrophotometric calibration along the slit should not be underestimated.

On some object data there is a sufficient amount of sky along the ends of the slit to determine a good night sky spectrum for two-dimensional sky subtraction purposes.

6.4. Data Reductions

A detailed description of using IRAF for spectroscopic CCD data reductions is the subject of Phil Massey’s *A User’s Guide to Reducing Slit Spectra with IRAF*. This is available in the IRAF documentation room in Tucson and in the IRAF Notebooks in each telescope control room.

=== THE MOUNTAIN SUN/IRAF SYSTEMS ===
• A PROVISO FOR USERS •

The installation of Sun workstations running IRAF has proven a great addition to the Observatory's data collection and reduction capabilities on the mountaintop. We have seen a sharp increase in the number of observers who use the Suns to, at least, get started with the data reduction process. Many observing proposals now have more than one observer on site with one person doing nothing but tending to the reduction of the previous nights observations.

Giving adequate support to this influx of data reduction activity is becoming a difficult support problem. Our current resources allow only one person for this duty and this is only part of his total responsibility. It is *not* possible to provide assistance to users on all days of the week, or at all hours of the day and night. Accordingly, we would like to warn users that *the mountaintop is not a fully supported IRAF site* and that response to requests for help with the Suns or IRAF will depend on the availability of support personnel. We will certainly do our best to do what we can to assist you, but there will be times when no support will be available. We make the following suggestions to users:

- Minimum expected level of knowledge: Some previous computer experience, preferably with the UNIX operating system and tape handling experience. Beginning level experience with IRAF is a plus. VMS is not used on Kitt Peak mountain.
- Learning IRAF and the optimum data reduction procedure is no small task. If you have *not* previously used IRAF, the mountaintop is not the best place to start learning unless you have made a fair effort to prepare in advance by reading the available "cookbooks" and talking with persons experienced with data reductions. Our resources do not allow for multi-hour "cold-start" teaching sessions with the uninitiated.
- The observer should know in advance what steps in the data reduction process he or she wishes to do. Our people can help you with the Sun and get you going in IRAF, but *the actual steps of the data reduction process are the responsibility of the observer*. Many of our support people can offer advice depending on their level of experience.
- If you experience difficulties with IRAF, and mountain support personnel are not available, call downtown IRAF support, Jeannette Barnes (8-381), or use the hotline (dial 9-323-4160). For less pressing questions/problems, use the IRAF Email service, i.e. "mail iraf@noao.edu". Jeannette Barnes is also willing to give introductory "tours" of IRAF downtown before your run, by pre-arrangement.

Your cooperation is appreciated.

7. APPENDICES

7.1. APPENDIX I. Telescope and Guider Software

These FORTH commands are entered on the telescope operator's DEC 11/44 terminal. The RC Spectrograph instrument "switch" is simply *rc*. Note that both the keyswitch and instrument power switch on the console must be turned on to run motors.

	gtn	Guider "nudge" for centering the guider-telescope precisely on a field. The routine will ask for the step size of the guide probe motion in arcsecs. The object will then move in step increments in the appropriate direction when N S E or W is typed. The step size must be less than 1.5 arcsecs..
	gp	Puts the telescope/guider into the probe mode where the handpaddle moves the guide probe.
<t.> <a.>	**bota**	Telescope blind-offset in time (seconds of α) and angle (δ arcseconds). Using the autoguider in closed-loop.
<a.> <a.>	**boaa**	Blind-offset in seconds of arc <a>. Using the autoguider in closed-loop.
<t.> <a.>	**tota**	Blind-offset in time (seconds of α) and angle (δ arcseconds). Open-loop offset not using autoguider.
	2m	Sets the Instrument Rotator mirror to position 2 for the light from the telescope to enter the spectrograph for observing.
	3m	Mirror position 3 for the wide field (4 arcmin) TV
	4m	Mirror position 4 for the comparison sources
	-comp	Sets system up for observing, i.e. moves the rotator mirror to position 2, comparison lens OUT, and turns calibration lamps OFF
	+comp	Sets the system up for a comparison calibration, i.e. moves the Rotator mirror to position 4, puts IN the comparison lens, turns ON the last selected lamp.
	cstat	Prints on the terminal the calibration source status, i.e. which lamp is selected, turned on and what the ND filter wheel position is.
	quartz	Selects the quartz lamp (port A) and asks if it should be turned on
	bpor	Selects the He-Ne-A lamp (port B) and asks if it should be turned on
	cpor	Selects the Th-A hollow-cathode (port c) and asks if it should be turned on
	cmi	Returns the selected source ND filter wheel to its fully attenuated index position.
	zmr	Initialize motor-ramper hardware after an abort

<n> **cnd** Sets the neutral density filter wheel on the selected source to <n>, where 0<n<76 for the quartz lamp and 0<n<114 for the He-Ne-A lamp. The clear position is n=0 . Normally the filter wheel box for the He-Ne-A lamp will be removed (to get more light) and the filter position will always read 114, a false indication of full attenuation.

7.2. APPENDIX II. Spectrograph Control Software

These commands are entered on the telescope operator's DEC 11/44 terminal.

sstat Prints out the status of all the components on the spectrograph. Also defined as '**q**' .

<n> **rsv** Moves rear slit viewer, 0=OUT, 1=IN

dksel Decker select, will ask for the normal decker or the special CryoCam decker. All subsequent commands will refer to the selected decker.

decker Asks for decker window needed and moves to it

<n> **dk** Jogs aperture plate motor by n steps

clin Move comparison lens IN

clout Move comparison lens OUT

<n> **clens** Move comparison lens, where n=0/1 for OUT/IN

<n> **f1** Moves upper filter bolt to position <n>, where <n> =

1 Clear
2 GG-495, 3mm
3 GG-420, 3mm
4 RG-610, 3mm
5 CuSO4, 8mm**

** Use only for long slit work, this filter is too small for multi-aperture work. ALWAYS CHECK THE FILTER BOLT FOR THE CURRENT CONFIGURATION, THE SELECTION OF FILTERS CAN CHANGE FROM RUN TO RUN.

<n> **f2** Moves lower filter bolt to position <n>, where , <n> =

1 Clear
2 0.0 mag. neutral density
3 2.5 mag. neutral density
4 5.0 mag. neutral density
5 7.5 mag. neutral density

<n> **sgrat** Set grating tilt to <n>.

<n> **col** Set collimator to position <n>.

<n> **slit** Set slit width to <n> microns ($12 \le n \le 16384$)

7.3. APPENDIX III. ICE Command Summary

For the complete documentation see: *An Observer's Guide to Taking CCD Data with ICE.*

obsinit	Clear the data directory and initialize the system for a new observer. Use under the UNIX prompt.
observe	Take a object, zero, dark, flat, or comp image
<n> mores	Repeat the last 'observe' <n> times
flpr	flush the process after a control-c abort
zero	Take a series of zero images
object	Take a series of object images
flat	Take a series of flat images
comp	Take a series of comp images
dark	Take a series of darks
test	Take a test image and overwrite the previous test image
detpars	Set the detector parameters for CCD format and gain
obspars	Set the observing parameters
telpars	Set the telescope parameters
instrpars	Set the instrument parameters, DISPAXIS=1 or 2
ccdinfo	List important CCD information
tele	Test SUN-TCP link for transmission of header data

Complete ICE documentation is available on-line using 'anonymous ftp'. Documentation resides on tucana, a SUN/UNIX workstation. The following will transfer the documentation across the network to your UNIX machine:

'ftp orion' or 'ftp 140.252.1.22'
Login as 'anonymous'
Enter your last name as the password
Change directories via 'cd kpno/manuals'
List files with 'ls -l', look for ice files
Set to binary transfer via 'binary'
Begin the transfer via 'get ice.ps.Z'
After completion, logoff via 'bye'
Uncompress the files via 'uncompress ice.ps.Z'
Printout the PostScript file on your laserwriter via 'lpr -Plw? ice.ps'

7.4. APPENDIX IV. Risley Prisms

Below is an article reprinted from the December 1992 NOAO Newsletter (No.32).

"Risley Prisms at the 4-m: Better than Nothing"

Although we all learned about differential atmospheric refraction back in Astronomy 101, the current generation of spectroscopists owes a debt to Filippenko (1982 PASP 94, 715) for reminding us exactly how severe the implications can be for spectrophotometry. With the proliferation of CCDs on Cassegrain spectrographs, it is not uncommon for an astronomer to [italics: believe] she/he is doing spectrophotometry with a 1.5-2.0 arcsec slit, when in fact much of the blue light is falling outside the slit. (Even at a "modest" airmass of 1.5, the light at 4000 [Angstrom] will be displaced by 0.7 arcsec relative to the light at 5000 [Angstrom].) Mark Phillips recently gave an excellent illustration of this in the December 1991 NOAO Newsletter (p. 17).

If the spectrograph slit is aligned with the direction of refraction (i.e., the line from the zenith to the horizon), then there is little wavelength-dependent light loss. However, aligning the slit with this "parallactic angle" can be a mild pain with most telescopes. At the 2.1-m, for instance, the telescope must be moved to the zenith and the spectrograph rotator adjusted by hand from the platform. Although the rotator at the 4-m can be controlled remotely from the control room, the telescope must be first slewed near the zenith in order to protect the rotator's bearings from too much strain. An alternative to rotating the slit is to use optics to compensate for refraction. These "atmospheric dispersion correctors" (ADCs) are an intrinsic part of the design of most modern telescopes, due in large part to the desire to use multi-object fiber feeds, for which alignment with the parallactic angle is meaningless since fibers ends tend to be round.

Many users of the 4-m telescope may be surprised to learn that in fact there are a pair of prisms available designed to act as ADCs. These "Risley prisms" can be inserted into the beam remotely using software commands, and are automatically rotated to compensate for atmospheric dispersion at a given telescope position, in principle. (Their field size is too small to be used with Hydra, however.) During two recent runs with the RC Spectrograph, two staff observing teams opted to use the Risleys.

Our experiments on standard stars suggest that the Risleys do help, but they do not do the whole job. The plot below shows the observed flux of the standard star Feige 110, calibrated by observations of a standard star near the zenith, observed both with and without the Risleys. The observed flux of Feige 110, obtained at an airmass of 2.2, is a reasonable match to that expected when the slit is rotated to the parallactic angle. (The two spectra at the top show the observations at the parallactic angle both with and without the Risleys; the small differences between these are due to small differences in the fit of the sensitivities curves.)

The bottom-most curve shows what would happen if we attempted to determine the flux of Feige 110 with the slit rotated 90 degrees to the parallactic angle. This is about the worst case imaginable, but would actually be what you are doing if you attempted to observe an object at a declination of -30 degrees on the meridian with the slit oriented east-west. (Our slit width was 1.8 arcsec for this experiment.) Filippenko's Table I reminds us that the light at 3500 [Angstrom] was displaced by 2.1 arcsec relative to that at 5000 [Angstrom]; we were lucky the seeing was poor, or we might not have gotten any UV light into the slit at all!

The middle spectrum shows how effective the Risleys were in this "horrible-case scenario." Clearly they help, and yet, it is also clear that they don't quite do the whole job, either. Note that the glass cannot match the atmospheric dispersion at all wavelengths, and so the prisms represent a compromise by the designer over some spectral range. Furthermore, the prisms introduce a small (approx. 7%) transmission loss above 4000 [Angstrom], which worsens to a 30% loss by 3700 [Angstrom].

We are planning to conduct further tests this spring, and substantiate that the Risleys are being aligned correctly. As we approach the era of the ADCs, it behooves us to understand the ones we already have. In the meantime, we recommend rotating to the parallactic angle to really "get it right."

Phil Massey, Todd Boroson, George Jacoby, Richard Green

See the plot in NOAO Newsletter #32 [Dec. 1, 1993], p. 27.

7.5. APPENDIX V. Spectrograph Setup Checklist

• R.C. SPECTROGRAPH SETUP CHECKLIST •

Kitt Peak National Observatory

Observers: **Date:**

4-Meter Telescope: f/8 , scale: 6.6245 "/mm

Slit Viewing Optics: ( ) RCA1.5:1 ( ) RCA1:1 ( ) Westinghouse

CCD Detector: T2KB (2048x2048) TI-__ (800x800)
Dispersion Along: ( ) rows or ( ) cols

CCD Parameters:	**Field Orientation:**
	Slit TV:
Data Format: _____ cols x _____ rows	
Bias Overscan: ____ cols ____ rows	
Pixsums in X,Y: _____x_____	
CCD Scale: _____ arcsecs/pixel	
Gain: _____ electrons/ADU	**IMTOOL Window:**
Readout Noise: _____ electrons	
Bias: mean _____ rms _____	
Preflash: Time:____ sec., Digit Switch:____	
Preflash Level:_____ ADU	

Spectrograph Parameters:	**Setup #1**	**Setup #2**
Grating No. & Order (I,II,III):	_____	_____
Tilt:	_____	_____
Order Separation Filter:	_____	_____
Slit Width (μ or "):	_____	_____
Collimator Focus:	_____	_____
UVF Camera Focus:	_____	_____
Dispersion (Å/pixel):	_____	_____
Central λ:	_____Å	_____Å
λ Coverage (low/high):	_____	_____
Resolution (pixels or Å):	_____	_____
Calibration Parameters:		
He-Ne-A or Th-A:	_____	_____
ND Wheel Setting:	_____	_____
Balancing Filter:	_____	_____
Exposure Time / Level:	_____	_____
Internal Quartz (faint/bright):	_____	_____
ND Wheel Setting:	_____	_____
Balancing Filter:	_____	_____
Exposure Time / Level:	_____	_____
Dome Flat: High/Low Banks:	_____	_____
Exposure Time / Level:	_____	_____

7.6. APPENDIX VI. Helium-Neon-Argon Line Identifications

From 'idhenear.dat' in the IRAF 'linelists' directory. Note that some features marked on the plots are not in this list.

3187.743	HeI
3464.14	AII(70)
3520.5	NeI 3520.472 blend with A 3520.0
3545.58	AII(70)
3559.51	AII(70)
3718.21	AII(131) blend with 3724.51 AII(131)
3729.29	AII(10)
3737.89	AII(131)
3780.84	AII(54)
3850.57	AII(10)
3888.646	HeI
3928.62	AII(10)
3964.727	HeI
4026.189	HeI
4044.418	AI(4)
4072.2	blend A 4072.01 and 4072.40
4131.73	AII(32)
4158.590	AI(2)
4259.361	AI(9)
4277.55	AII(32) blend with AI(4) 4272.168
4300.4	AI(4) blend
4426.01	AII(7)
4471.477	HeI
4510.733	AI(9)
4545.08	AII(15)
4579.39	AII(17)
4657.94	AII(15)
4713.143	HeI
4764.89	AII(15)
4806.07	AII(6)
4879.90	AII(14)
4921.929	HeI
4965.12	AII(14)
5015.675	HeI
5187.746	AI
5221.270	AI
5400.562	NeI(3)
5495.872	AI(14)
5572.548	AI
5606.732	AI
5650.703	AI(12)
5748.299	NeI(13)
5764.418	NeI(13)
5852.4878	NeI(6)
5875.618	HeI
5944.8342	NeI(1)
6029.9971	NeI(3)
6074.3377	NeI(3)
6096.1630	NeI
6143.0623	NeI(1)
6163.5939	NeI(5)
6217.2813	NeI(1)
6266.4950	NeI(5)
6304.7892	NeI
6334.4279	NeI(1)
6382.9914	NeI(3)
6402.246	NeI(1)
6506.5279	NeI(3)
6532.8824	NeI
6598.9529	NeI(6)
6678.2	blend HeI 6678.149 with NeI 6678.2764

6717.0428	NeI
6752.832	AI(11)
6871.290	AI
6929.468	NeI(6)
6965.430	AI(1)
7032.4127	NeI(1)
7065.188	HeI
7107.496	AI
7125.80	AI
7147.041	AI(1)
7173.939	NeI(6)
7206.986	AI
7245.167	NeI(3)
7272.936	AI
7281.349	HeI
7311.71	AI
7353.316	AI
7372.118	AI
7383.980	AI
7438.899	NeI
7488.872	NeI
7503.867	AI(8)
7514.651	AI
7535.775	NeI
7544.046	NeI
7635.105	AI(1)
7670.04	AI
7723.8	blend AI(1) 7723.760 and AI(6) 7724.206
7891.075	AI
7948.175	AI(6)
8006.156	AI(3)
8012.000	AI Blend of 8006 and 8014 for low dispersion
8014.786	AI(1)
8053.307	AI
8082.458	NeI(6)
8103.692	AI(3)
8110.000	AI Blend of 8103 and 8115 for low dispersion
8115.311	AI(1)
8264.521	AI(8)
8300.326	NeI(12)
8377.607	NeI(12)
8424.647	AI(3)
8495.360	NeI(18)
8521.441	AI(8)
8605.78	AI
8620.47	AI
8634.648	NeI(23)
8654.383	NeI(33)
8667.943	AI(6)
8761.72	AI
8780.622	NeI(27)
8782.1872	Low disp. blend of 8780.622 and 8783.755
8783.755	NeI(38)
8853.866	NeI(27)
9075.42	AI
9122.966	AI(1)
9148.68	NeI(30)
9194.68	AI
9224.498	AI(8)
9291.58	AI
9354.218	AI(8)
9425.38	NeI(36)
9534.167	NeI(38)
9657.784	AI(3)
9784.501	AI(8)

Spectral plots only available on paper copy.

4–METER TELESCOPE – R.C. SPECTROGRAPH
– – OPTICAL DIAGRAM – –

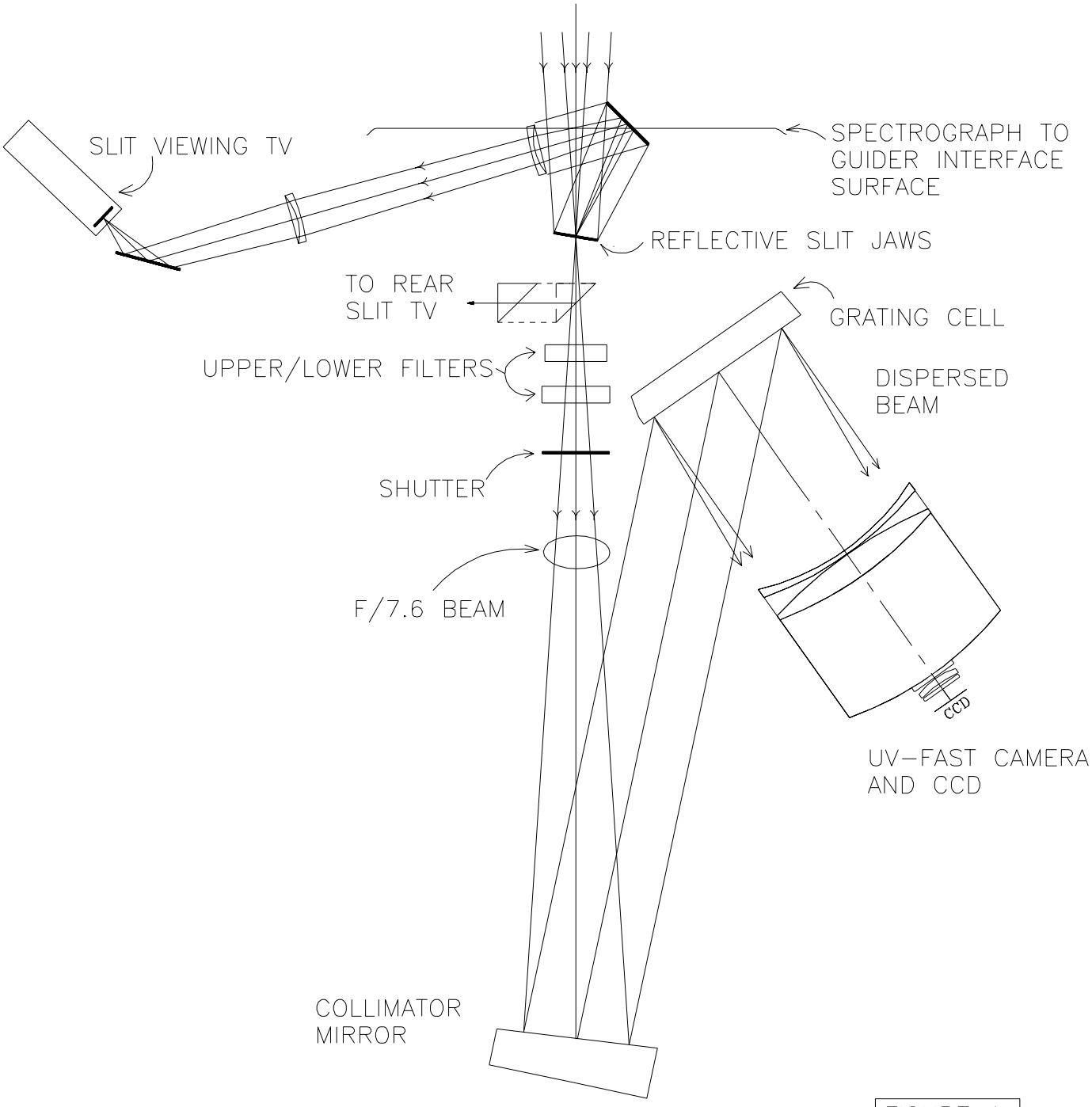
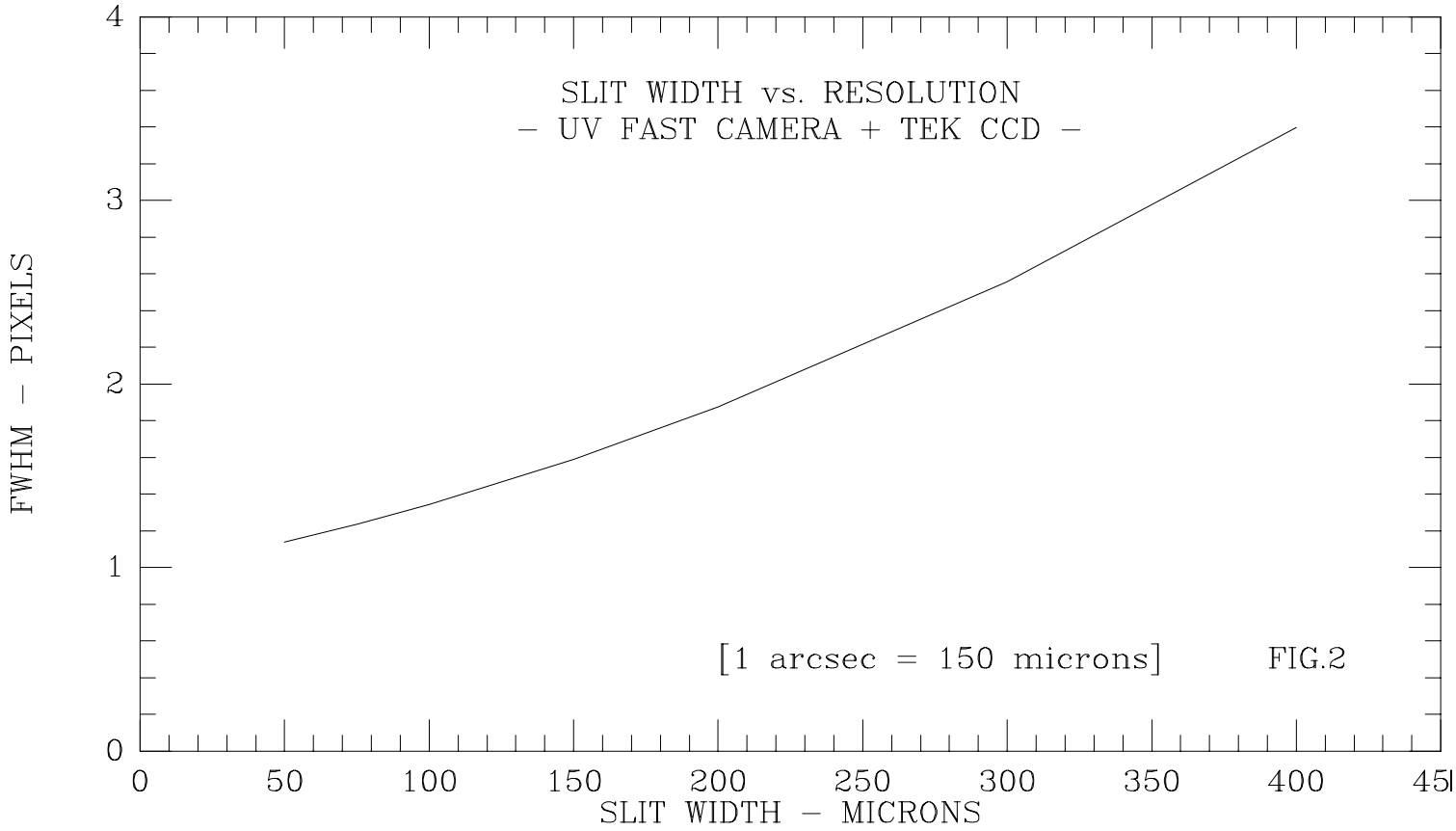
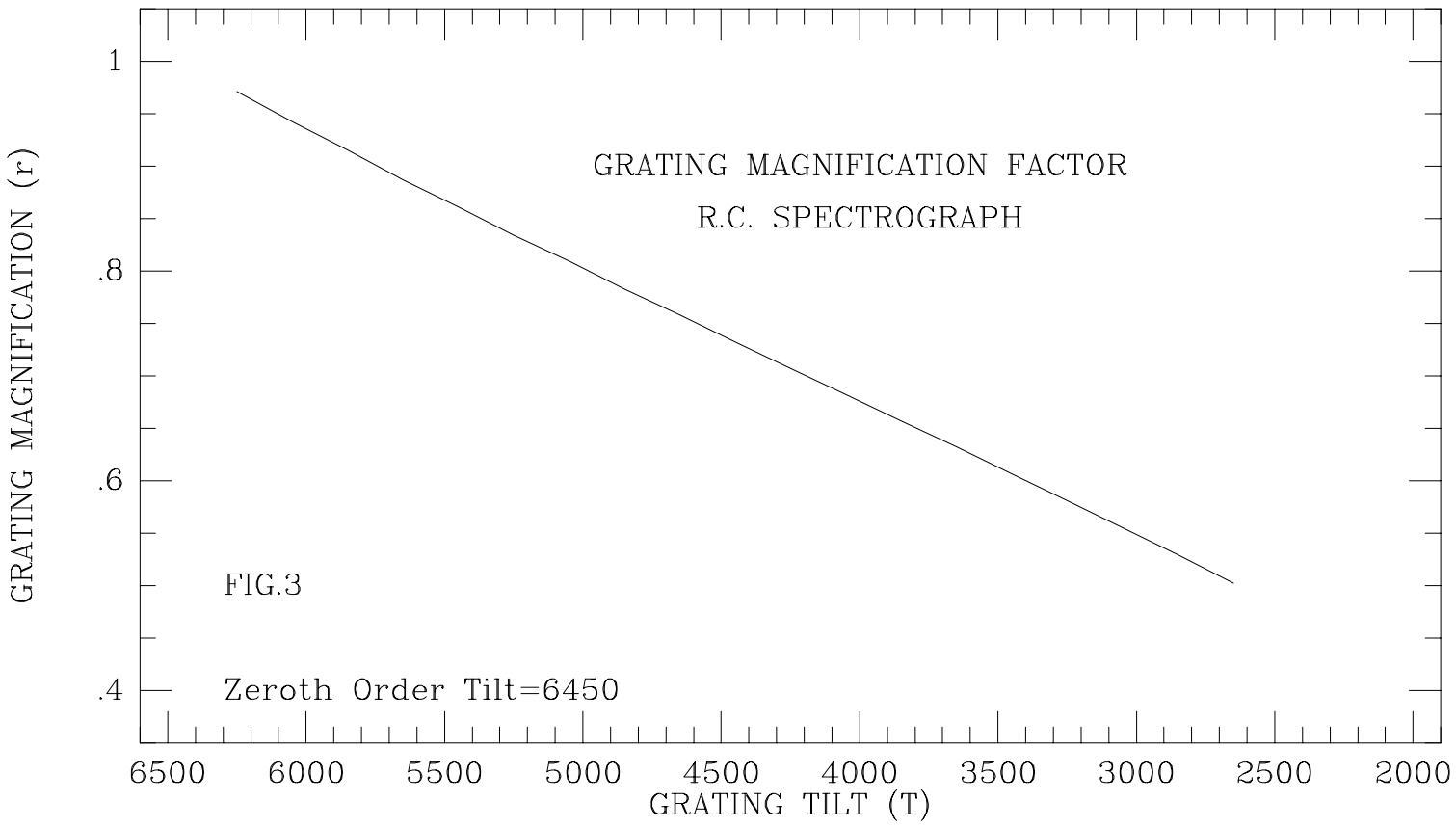
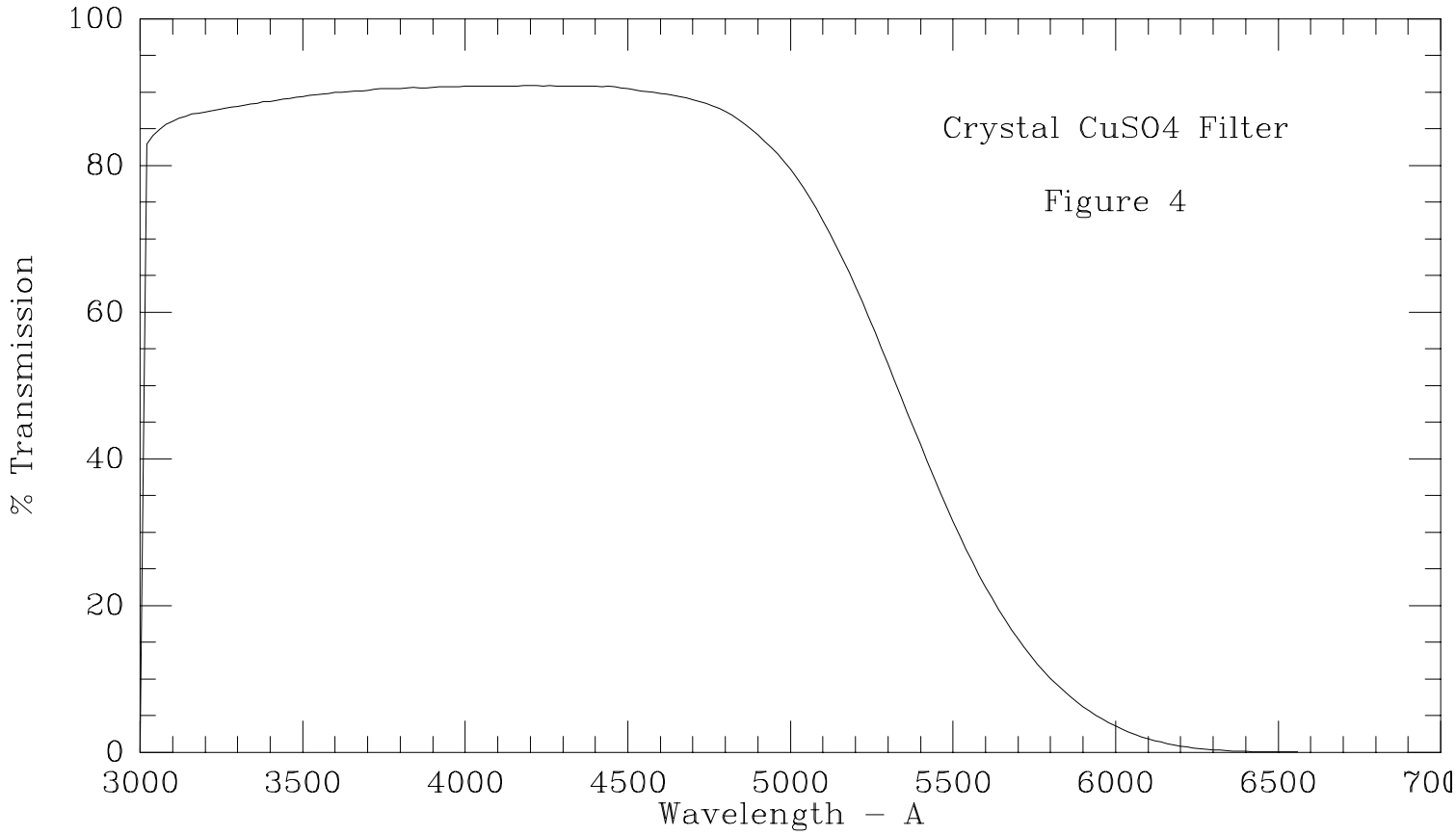
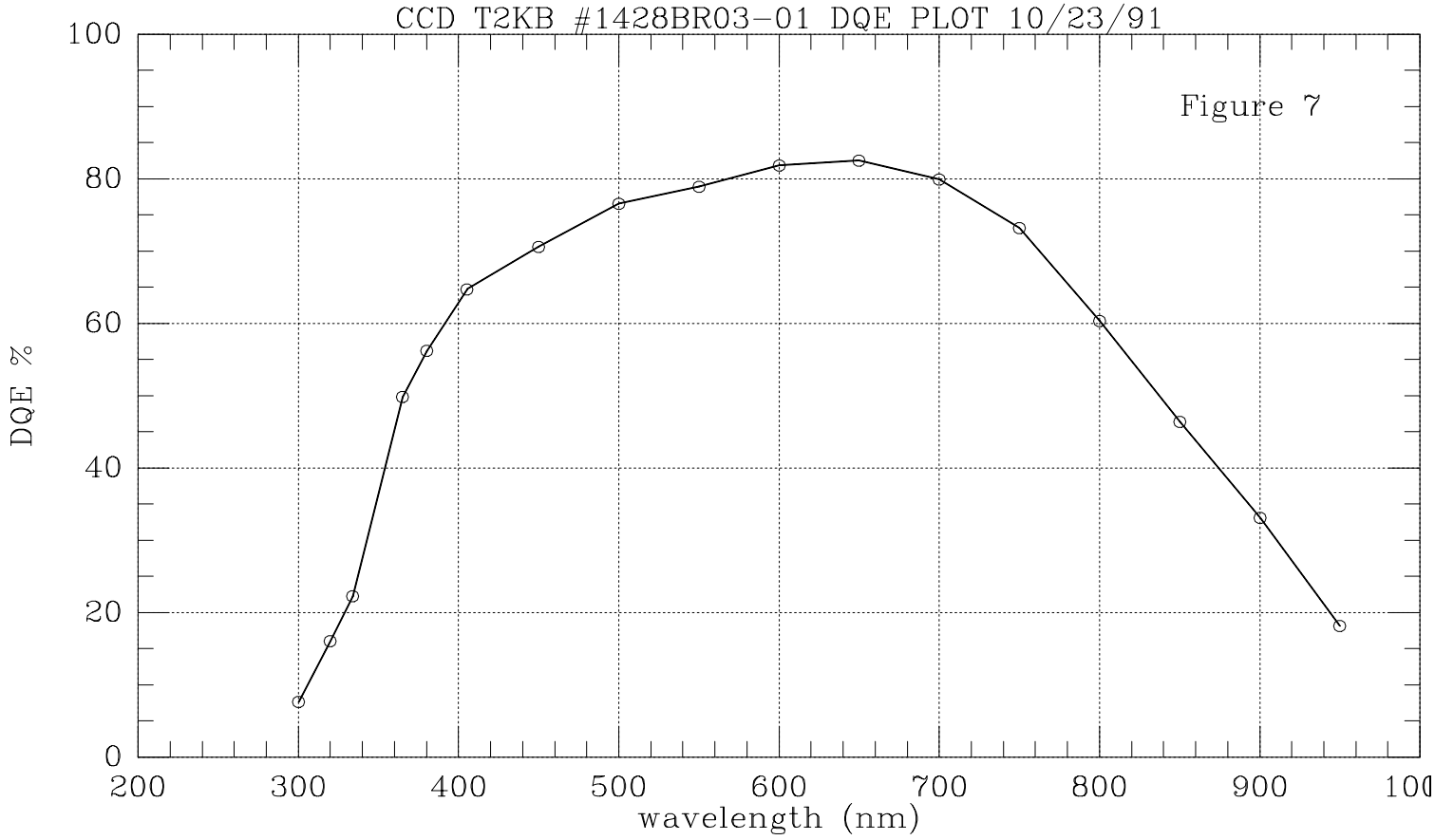


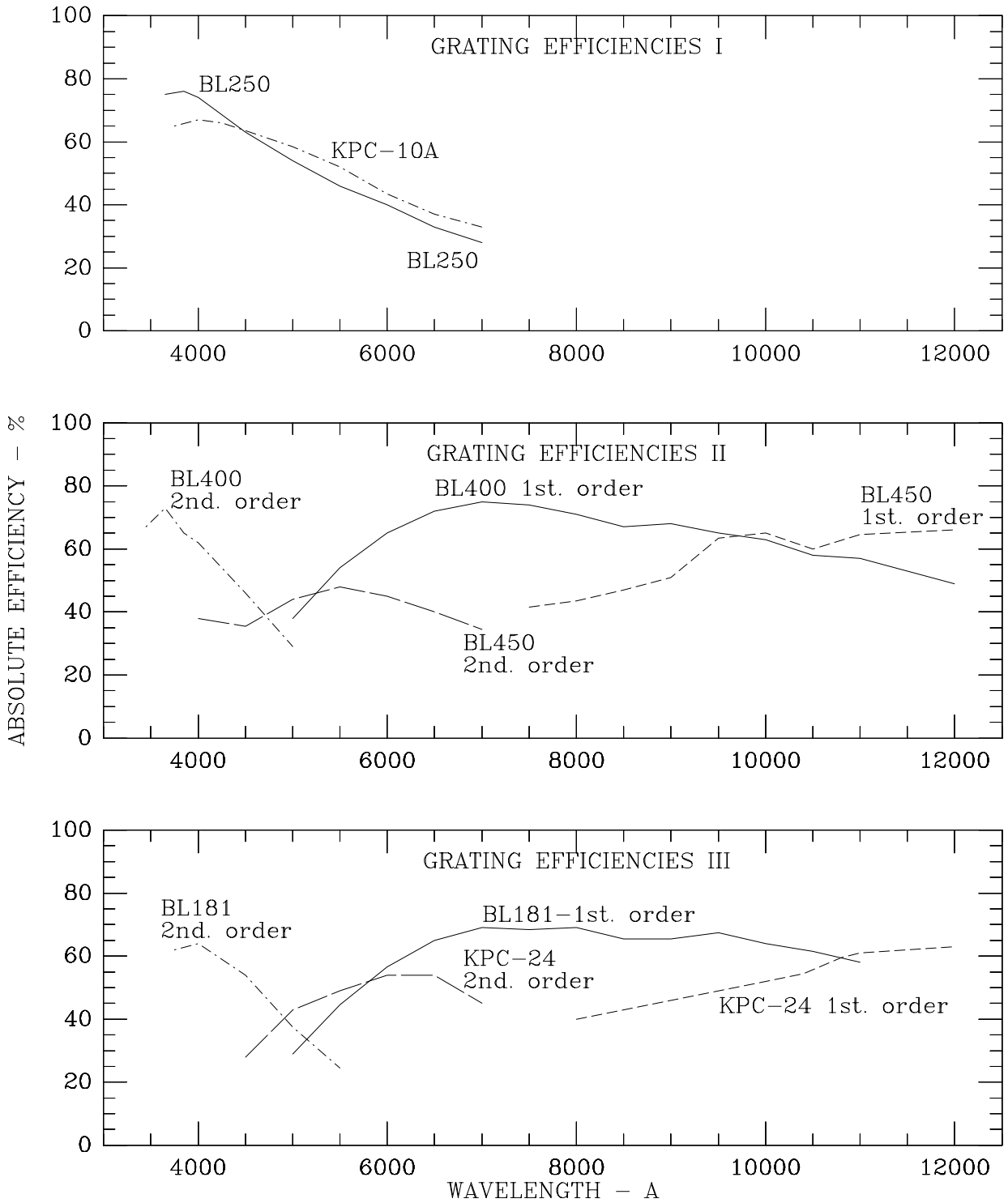
FIGURE 1.

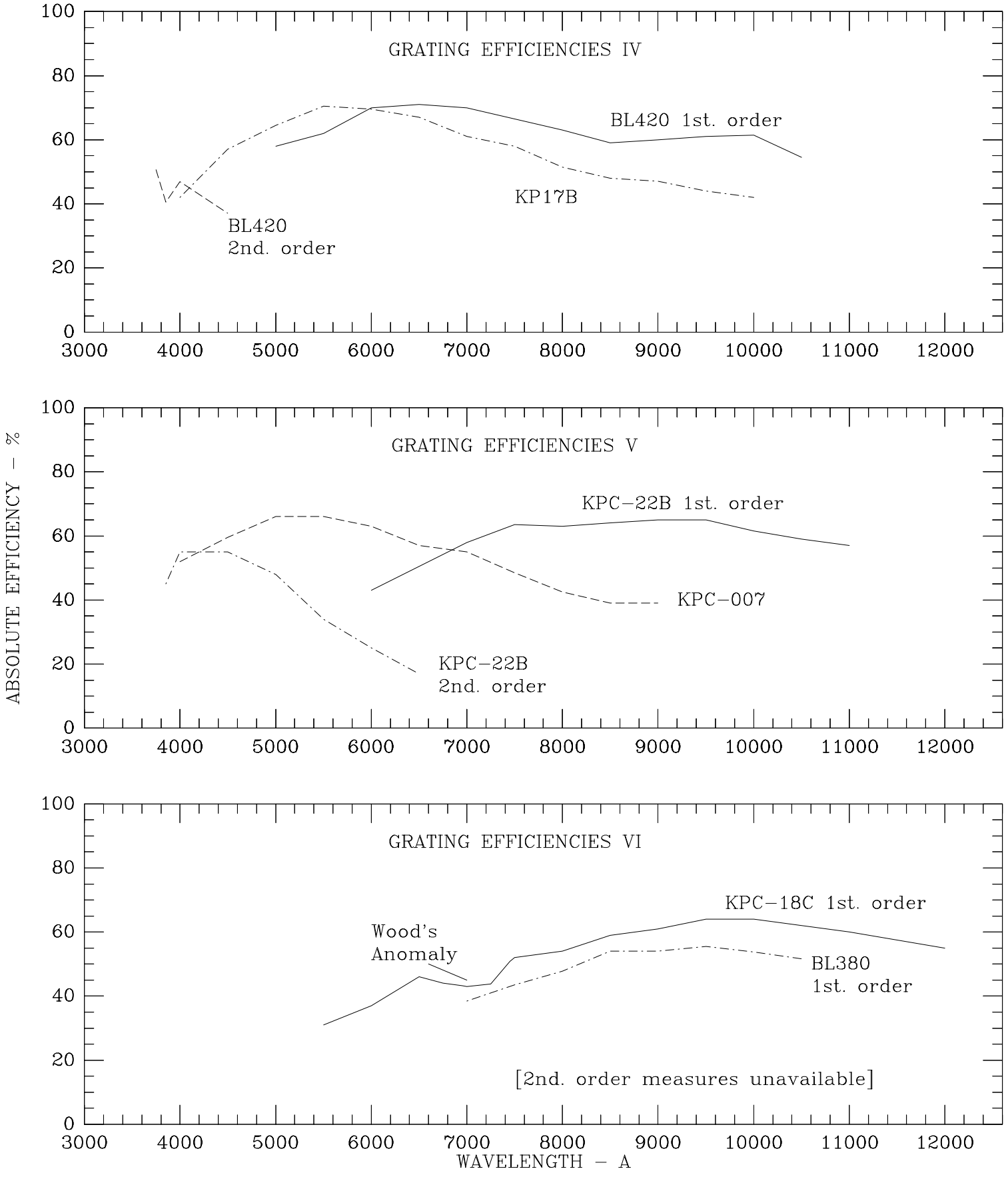

SLIT WIDTH vs. RESOLUTION
– UV FAST CAMERA + TEK CCD –
FWHM – PIXELS
SLIT WIDTH – MICRONS
[1 arcsec = 150 microns]
FIG.2
0
1
2
3
4
0
50
100
150
200
250
300
350
400


GRATING MAGNIFICATION FACTOR
R.C. SPECTROGRAPH
GRATING MAGNIFICATION (r)
GRATING TILT (T)
FIG.3
Zeroth Order Tilt=6450
.4
.6
.8
1
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000


Crystal CuSO4 Filter
Figure 4
% Transmission
Wavelength - A
100
80
60
40
20
0
3000
3500
4000
4500
5000
5500
6000
6500


CCD T2KB #1428BR03-01 DQE PLOT 10/23/91
Figure 7
DQE %
wavelength (nm)
100
80
60
40
20
0
200
300
400
500
600
700
800
900


GRATING EFFICIENCIES I
BL250
KPC−10A
BL250
GRATING EFFICIENCIES II
BL400
2nd. order
BL400 1st. order
BL450
1st. order
BL450
2nd. order
GRATING EFFICIENCIES III
BL181
2nd. order
BL181−1st. order
KPC−24
2nd. order
KPC−24 1st. order
ABSOLUTE EFFICIENCY − %
WAVELENGTH − A
0
20
40
60
80
100
4000
6000
8000
10000
12000


GRATING EFFICIENCIES IV
BL420 1st. order
KP17B
BL420
2nd. order
GRATING EFFICIENCIES V
KPC-22B 1st. order
KPC-007
KPC-22B
2nd. order
GRATING EFFICIENCIES VI
KPC-18C 1st. order
Wood's
Anomaly
BL380
1st. order
[2nd. order measures unavailable]
ABSOLUTE EFFICIENCY - %
WAVELENGTH - A
0
20
40
60
80
100
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000