



EUROPEAN SOUTHERN OBSERVATORY

OPERATING MANUAL

No. 8 – March 1989



THE COUDÉ ECHELLE SPECTROMETER THE COUDÉ AUXILIARY TELESCOPE

The Coudé Echelle Spectrometer The Coudé Auxiliary Telescope

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Contents

1	Introduction	1
2	System description	2
2.1	General description	2
2.2	The CAT	2
2.3	3.6 m fiber link	5
2.4	The CES	5
2.4.1	Predisperser area	6
2.4.2	The single pass scanner	9
2.4.3	The double pass scanner	13
2.4.4	The Maksutov Long Camera mode	13
2.4.5	The Short Camera mode	16
2.5	Detectors	16
2.5.1	The scanner photomultiplier	16
2.5.2	The CCD	16
2.5.3	The Reticon	19
2.6	Software	19
3	CES Operating Procedure	24
3.1	Introduction	24

3.2	The Long Camera Reticon mode	24
3.2.1	Starting up	24
3.2.2	Calibration exposures	26
3.2.3	Science exposures	36
3.2.4	Closing down	38
3.3	The CCD mode of the Long and Short Camera	39
3.3.1	Starting up	39
3.3.2	Calibration exposures	39
3.3.3	Science exposures	41
4	Trouble-shooting	42
4.1	In case of problems	42
4.2	Currently known problems	42
5	Instrument performance	44
5.1	Total efficiency	44
5.2	Expected S/N ratios	45
5.3	Spectral resolution	45
5.4	3.6 m fiber link	45
6	CAT operating procedure	49
6.1	Starting up	49
6.2	Telescope pointing and guiding	52
6.3	Closing down	52
	Bibliography	53

List of Tables

2.1	Spectral Coverage of the CES	18
5.1	Efficiency of the CES + CAT	44
5.2	Spectral Resolution of the CES	48

List of Figures

2.1	Mechanics of the CAT	3
2.2	CAT Sky Coverage	4
2.3	The Coudé Echelle Spectrometer	7
2.4	CES Optical Arrangement	8
2.5	Optical Schematic of the Slit Environment	10
2.6	Spectral response of slit view TV camera and transmission curves of slit view filters.	11
2.7	Optical Arrangement of Predisperser	12
2.8	Scanning Mode of the CES	14
2.9	Grating Turn-table Operating Principle	15
2.10	The Long Camera	17
2.11	The Short Camera	20
2.12	Responsivity and Quantum Efficiency of the Quantacon Tube.	21
2.13	CCD #9 Features.	22
2.14	Relative Response Curve of the Reticon.	23
5.1	Expected S/N ratios for the Short Camera and CCD #9.	46
5.2	Expected S/N ratios for the Long Camera and CCD #9.	47

Chapter 1

Introduction

This manual describes the different configurations of the Coudé Echelle Spectrometer as well as the operation of the Coudé Auxiliary Telescope. It is intended to serve as a guide both during the preparation and execution of an observing program.

The CES is a rather complex instrument with numerous computer controlled functions. In order to achieve the best possible observing result, it is essential to understand the operation of the instrument in some detail. Prior to the start of the observing run, this manual should be studied. Long experience has demonstrated the importance of careful preparations during the afternoon before the start of the actual observations. This is especially true before the first night of an observing run. The various functions of the CES should be tried out as soon as possible after the instrument has been made available to the observer.

The CES is currently operated in the following configurations:

- The Long Camera mode with a Reticon or CCD as detector.
- The Short Camera mode with a CCD.
- The single or double pass scanner mode with a photomultiplier as detector.

The CES can also be used together with the 3.6 m telescope via a fiber optics link.

An overview of the system is given for each of the configurations as well as a step by step description of the actual handling of the CES and the CAT. The expected instrument performance is presented together with hints on observing techniques. We strongly encourage users to make any comments and suggestions concerning this manual in order that we may refine future versions. Please do this by firstly writing on a copy of this manual which you will find in the control room of the telescope and secondly in your observing report to be completed at the end of your observing mission to La Silla.

Chapter 2

System description

2.1 General description

The CES was designed by D. Enard and M. Le Luyer [1] and was installed at La Silla in 1980. It began operation in the scanner mode. Shortly thereafter observations started with the Maksutov Long Camera and an 1872 pixel reticon array. In 1982 the first tests were made using a fiber optics link from the 3.6 m telescope's prime focus to the CES in its double pass scanner mode [2]. A major step towards fainter magnitudes was taken in 1986 with the arrival of the Short Camera, designed by B. Delabre [3] and equipped with a high resolution CCD as detector. Finally, in 1987 a CCD was also installed with the Long Camera allowing high resolution observations of faint stars. Since 1987, the CES has been offered on a regular basis as a remotely controlled facility from ESO headquarters in Garching.

The CES employs a classical Czerny-Turner grating mount with a 204×408 mm echelle grating of 79 gr/mm as the dispersive element. The order separation is made by a prism pre-monochromator also mounted in a Czerny-Turner configuration. For maximum efficiency from the UV to the near IR, two optimized light-paths are available: one for the red and one for the blue. The spectrograph is highly automated; only the initial set-up, choice of camera, focusing, and path selection have to be made manually.

2.2 The CAT

The CES was originally designed to be fed either from the Coudé focus of the 3.6 m or from a 1.4 m Coudé Auxiliary Telescope (CAT) located in a separate building. The CAT is an Alt-Alt telescope with a Nasmyth focus (Fig. 2.1). Four secondary mirrors with different coatings are mounted in a turret. Two coatings are dielectric and partly overlapping in their useful wavelength range; the blue should be used below 5500 Å, the red above 4500 Å. A third secondary has a normal aluminium coating suitable for a wide wavelength range, a fourth is used for special

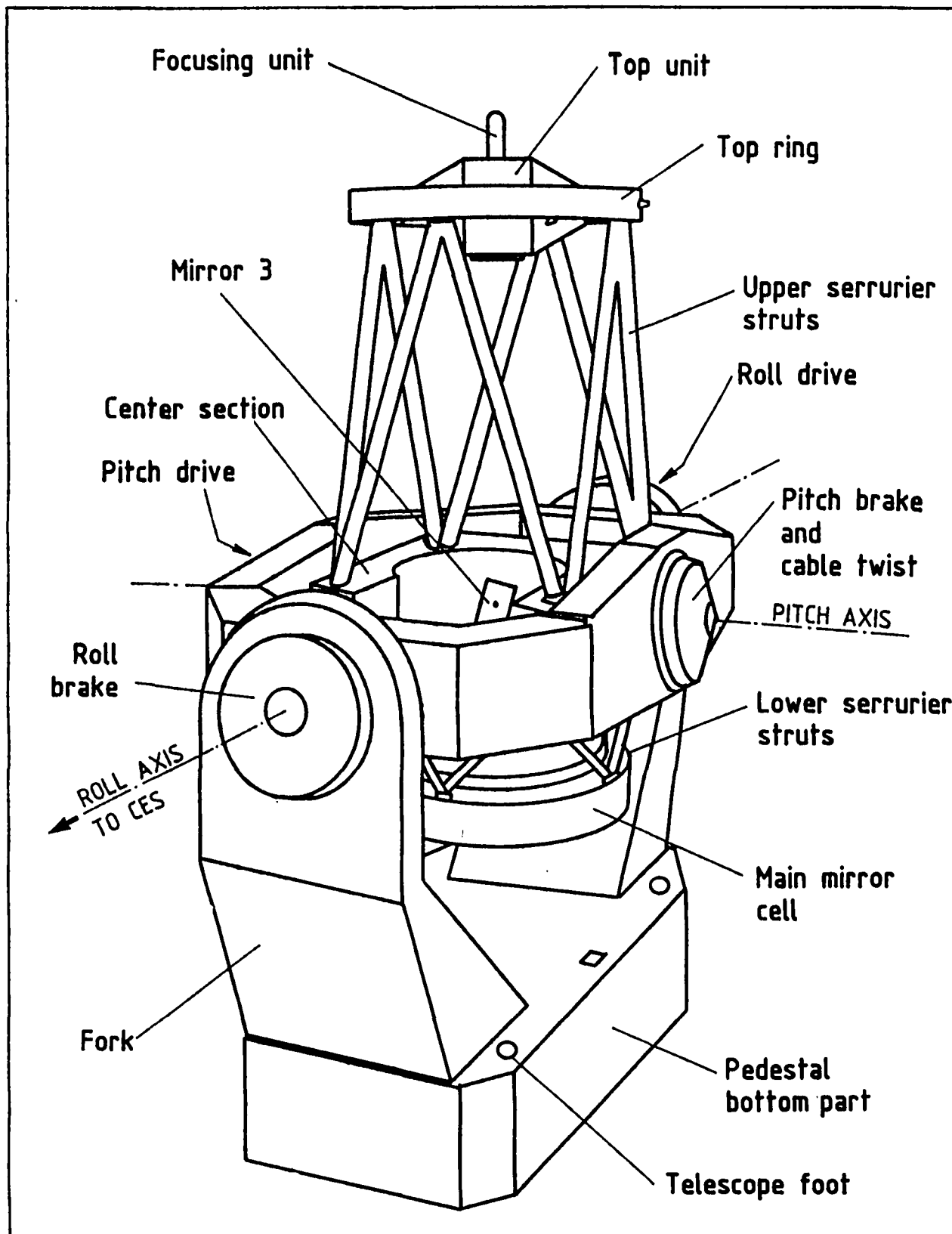


Figure 2.1: Mechanics of the CAT

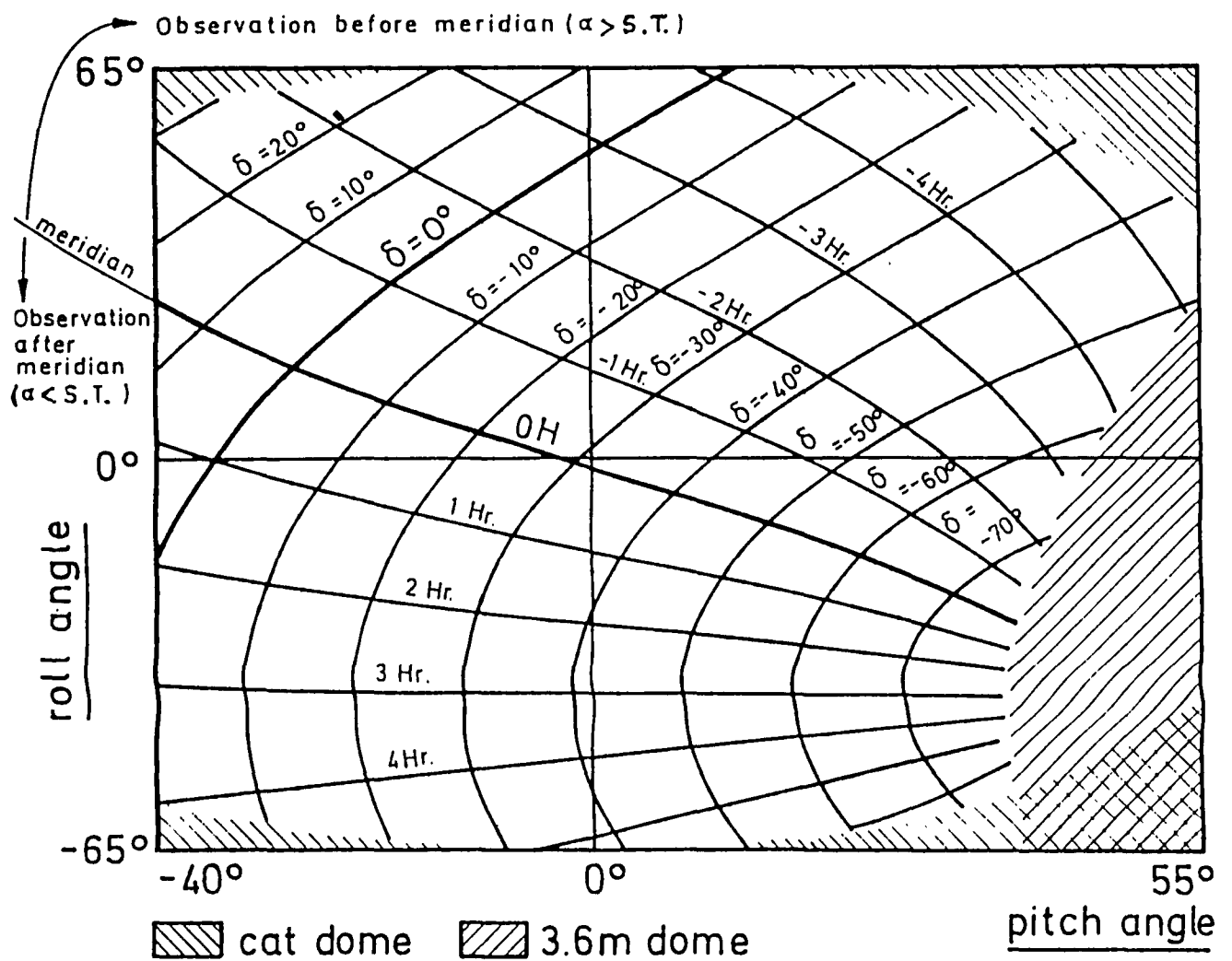


Figure 2.2: CAT Sky Coverage

purposes. The mirror selection is made from the CAT/CES control room. The flat movable third mirror sends a $f/120$ beam towards the focal reducer. The beam is inclined $2^{\circ}3'$ from the horizontal. Due to the Alt-Alt mount of the CAT and the use of the Nasmyth focus, field rotation is present at the focal plane.

A finder telescope mounted on the CAT shows a large field view of $20'' \times 26.5'$ on a TV monitor in the control room.

Restrictions on the CAT pointing coverage are imposed by the short distance between the CAT tower and the 3.6 m building. Objects outside the frame of Fig. 2.2 or inside the hatched areas can not be reached. Thus, problems may arise for stars with declinations south of -75° , where the 3.6 m dome may obscure. Furthermore, when the telescope is pointing towards higher northern declinations, additional limitations are created by the grazing reflection of the beam off mirror 3. Since the CAT roll axis is not strictly oriented in the north-south direction, a meridional asymmetry is present in Fig. 2.2. This is important for objects north of $+10^{\circ}$ which should be observed before the meridian.

2.3 3.6 m fiber link

The CES has also been used fed by the 3.6 m via a fiber optics link initially installed at the prime focus. First tests were made with the Maksutov Long Camera and the Reticon [2], later improvements included the use of an image slicer [5]. Gains in sensitivity of the order of 1.5 mag over the classical CAT/CES combination were obtained.

Successful observations of very high spectral resolution and S/N ratios have also been performed with the CES in its double pass scanner mode [6].

The latest tests have shown the advantage of using the Cassegrain focus as feed for the optics fiber [9]. As from April 1988 this configuration is offered to the user community. Here the fiber is fixed with a special connector at the centre of a plate mounted on the OPTOPUS adapter. The $f/8$ cassegrain beam is fed into the fiber via a microlens with an aperture of $3.4''$. At the output of the 35 m long fiber the beam is converted to $f/32$. An image of the core of the fiber, 2.2 mm in diameter, is formed on an image slicer. This generates an artificial slit $360 \mu\text{m}$ wide and 15 mm long at the focal plane of the CES.

2.4 The CES

Figs. 2.3 and 2.4 show the general layout of the CES. Additional information can be found in reference [1].

The $f/120$ beam from the CAT is changed by a two-element focal reducer to the CES $f/32.3$ aperture. The focal reducer is located in front of the slit area and uses four specially coated lenses, two for the blue path and two for the red. The lenses are mounted on two turrets which must be manually rotated to bring the selected lens into the light-path.

Fig. 2.5 shows the slit area and the focal reducer. The slit is continuously adjustable in width ($50\text{ }\mu\text{m}$ to 5 mm) and height (max. 30 mm). The scale is 0.226 mm/arcsec . To facilitate guiding the slit unit is slightly tilted. The stellar image reflected off the slit jaws can be seen from the control room with the help of a TV system. A flat mirror may be switched into the light-path after the focal reducer to give a view of the sky through the CAT telescope (Large Field). This mode is used to find and center the star on the TV monitor. Moving the mirror out of the light-path allows the star to be centered on the slit (Small Field). The large field has a size of 3.2×2.3 with a direct field orientation; the small field covers $62'' \times 46''$ in reversed orientation. Field rotation is clockwise in the large field and anticlockwise in the small field.

An eyepiece mounted close to the TV camera in the slit room may be used to view the slit or the large field visually. This may be useful, for example, to locate bright stars during daytime. The lever situated to the right of the eyepiece has to be in its outer position. A wheel in front of the TV camera holds three filters, "blue", "green" and "red". A fourth position, "white" is open, and a fifth, "black" is closed. Normally the open position may be used for autoguiding at all wavelengths. If observations are made at large zenith distances, the colored filters corresponding to the wavelength range under investigation should be used to avoid problems with atmospheric differential dispersion. The filters may also be useful to identify blue or red stars (see Fig. 2.6).

Seven calibration lamps are available on the CES. The two most commonly used are the Thorium hollow cathode lamp (No. 2) for wavelength calibration and the Quartz Iodine lamp (No. 6) for flat field correction. The selection between the lamps is made by a small rotating prism mounted at the center of the lamp turret assembly. This prism sends the light to a 45° mirror which can be inserted into the main light-path to illuminate the slit. A wheel between the prism and the 45° mirror holds a number of neutral filters ranging in density from 0 to 4. The lamp assembly is automatically set and controlled by the MULTI or SCAN programs when a calibration exposure is defined.

2.4.1 Predisperser area

The predisperser is a prism monochromator mounted in a quasi Czerny-Turner configuration used to isolate the correct echelle grating order. Fig. 2.7 shows the optical elements.

The $f/32.3$ beam from the slit is reflected by the collimator mirror and then refracted by the 22° Littrow prism towards the predisperser camera mirror. A spherical field mirror with a large radius of curvature ($R = 10.6\text{ m}$) sends the light toward the predisperser exit slit, the collimator, and the echelle grating. It images the telescope pupil on the grating and changes the aperture of the beam to $f/29$.

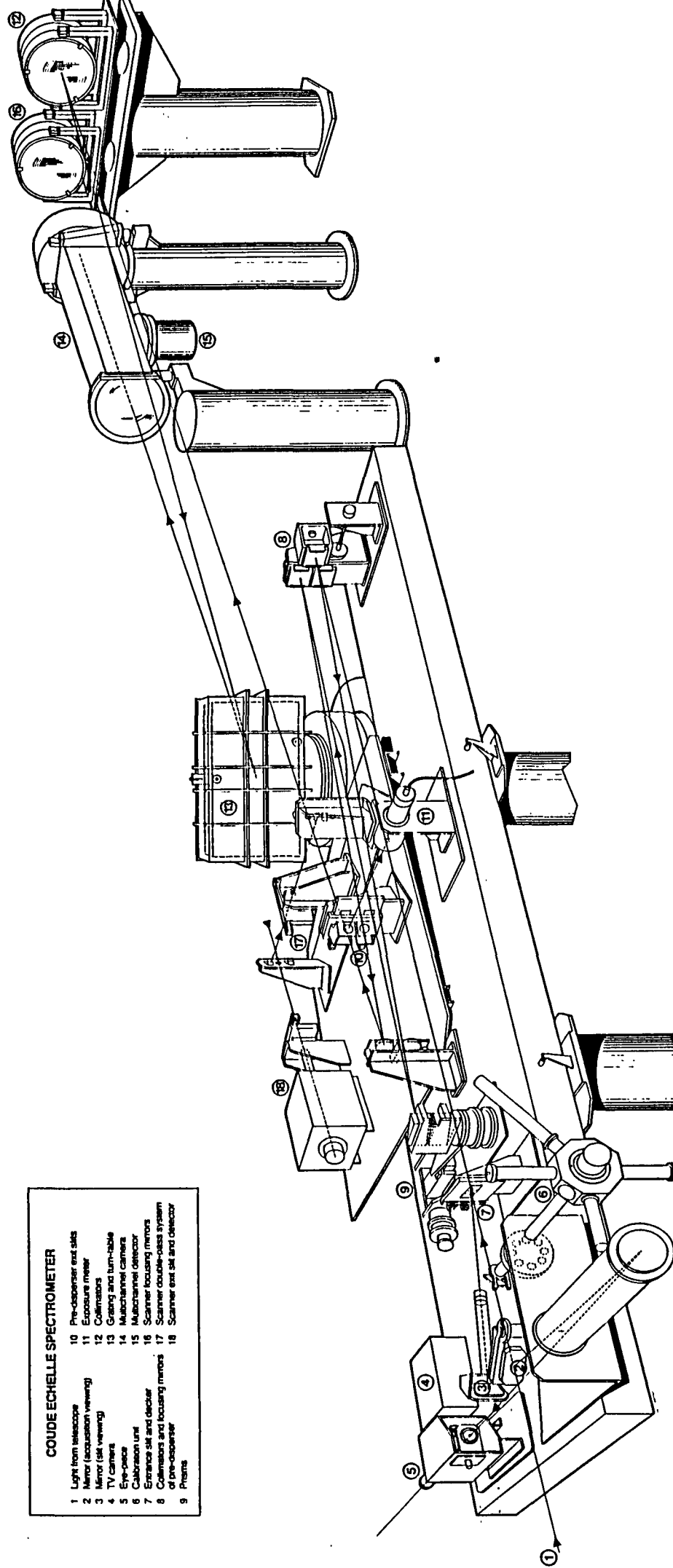


Figure 2.3: The Coude Echelle Spectrometer

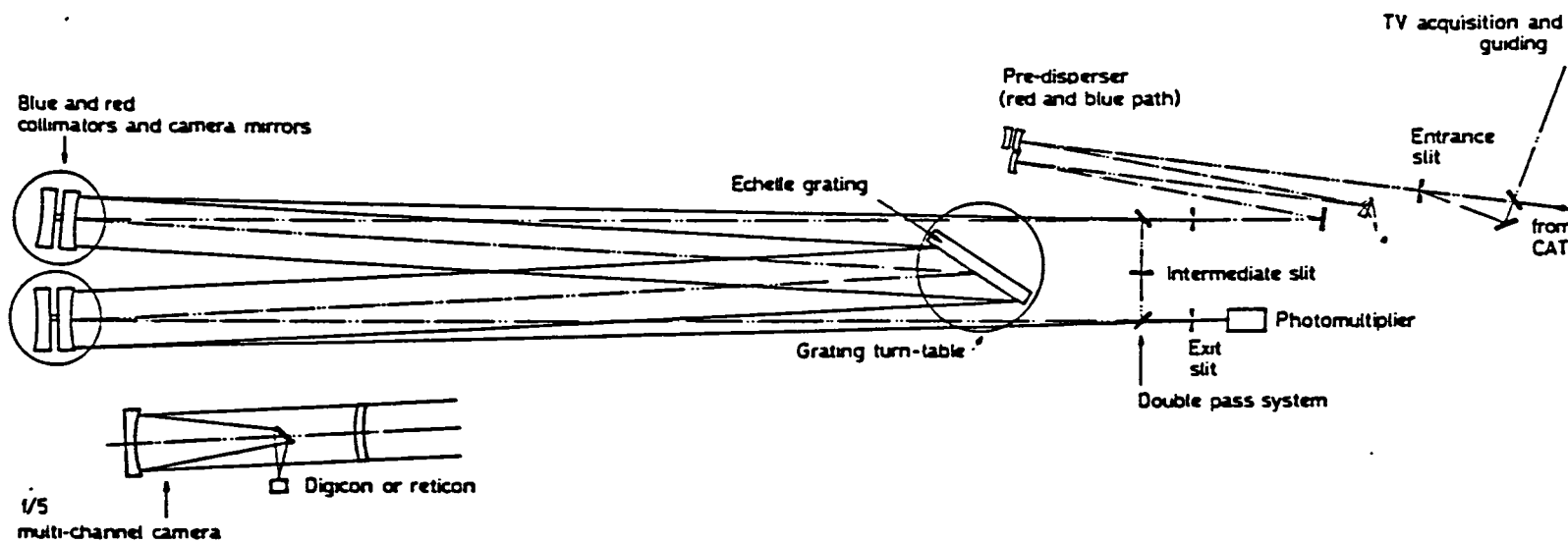


Figure 2.4: CES optical arrangement

The width of the predisperser exit slit is calculated and set by the control program to a value that ensures that almost no light outside the wavelength range registered by the CES detector enters the spectrograph. This range is a function of wavelength and set-up configuration. The result is that the level of scattered light is extremely low which in turn means a cleaner instrumental profile.

The part of the spectrum created by the predisperser which falls outside the wavelength range under study is deflected at the exit slit towards a photomultiplier which serves as an exposure meter. Obviously, the reading from this ratemeter depends strongly, not only on the central working wavelength, but also on the spectral type of the stars observed. It should thus be calibrated for every central working wavelength.

The blue and red predisperser collimator mirrors are mounted on a rotatable turret. When in use, these two mirrors are slightly differently inclined to allow the light to be reflected to the appropriate red or blue prism. All optical elements in the predisperser are duplicated. Thus there are two prisms, two camera mirrors, two field mirrors, two deflecting mirrors, and two exit slits. All mirrors are coated; the wavelength limit between the two paths falls around 5200 Å. The two field mirrors are oriented in such a way that the red and blue beams converge at the same place on the echelle collimator mirror.

2.4.2 The single pass scanner

Fig. 2.8 shows the optical elements of the single and double pass scanner (See also Fig. 2.4).

After the exit slit of the predisperser the $f/29$ beam encounters the main spectrograph collimator. This collimator is double, one red and one blue are mounted back to back on a common turntable. The focal length is 5800 mm and the diameter 300 mm.

The echelle grating is mounted in a close Littrow configuration; the angle between the incident and diffracted beam is only $5^{\circ}42'$. It has a size of 204×408 mm and is ruled with 79 gr/mm at a blaze angle of $63^{\circ}26'$. The diffracted beam from the grating is focussed by the camera mirror on an exit slit mounted in front of a photomultiplier tube.

In the scanner mode, the spectral range under investigation is swept by wobbling the grating. The grating is mounted on a turntable supported by high precision air bearings ensuring virtually frictionless operation. The position of the table is monitored by a radial Moiré fringe system to a resolution of $0''.1$. Typical scanning frequencies lie between 2 and 5 Hz. Fig. 2.9 shows a schematic representation of the operating principle of the turntable.

After the central wavelength, the resolving power, and the number of channels have been specified, the SCAN program calculates all relevant instrument parameters. It selects the correct diffraction order (Table 1) and positions the grating table and the predisperser prism. All slit widths are calculated and set. The final exit slit width is set equal to the projected entrance slit width. The angular channel width (resolution) and the optimal scanning frequency for the wavelength range are determined.

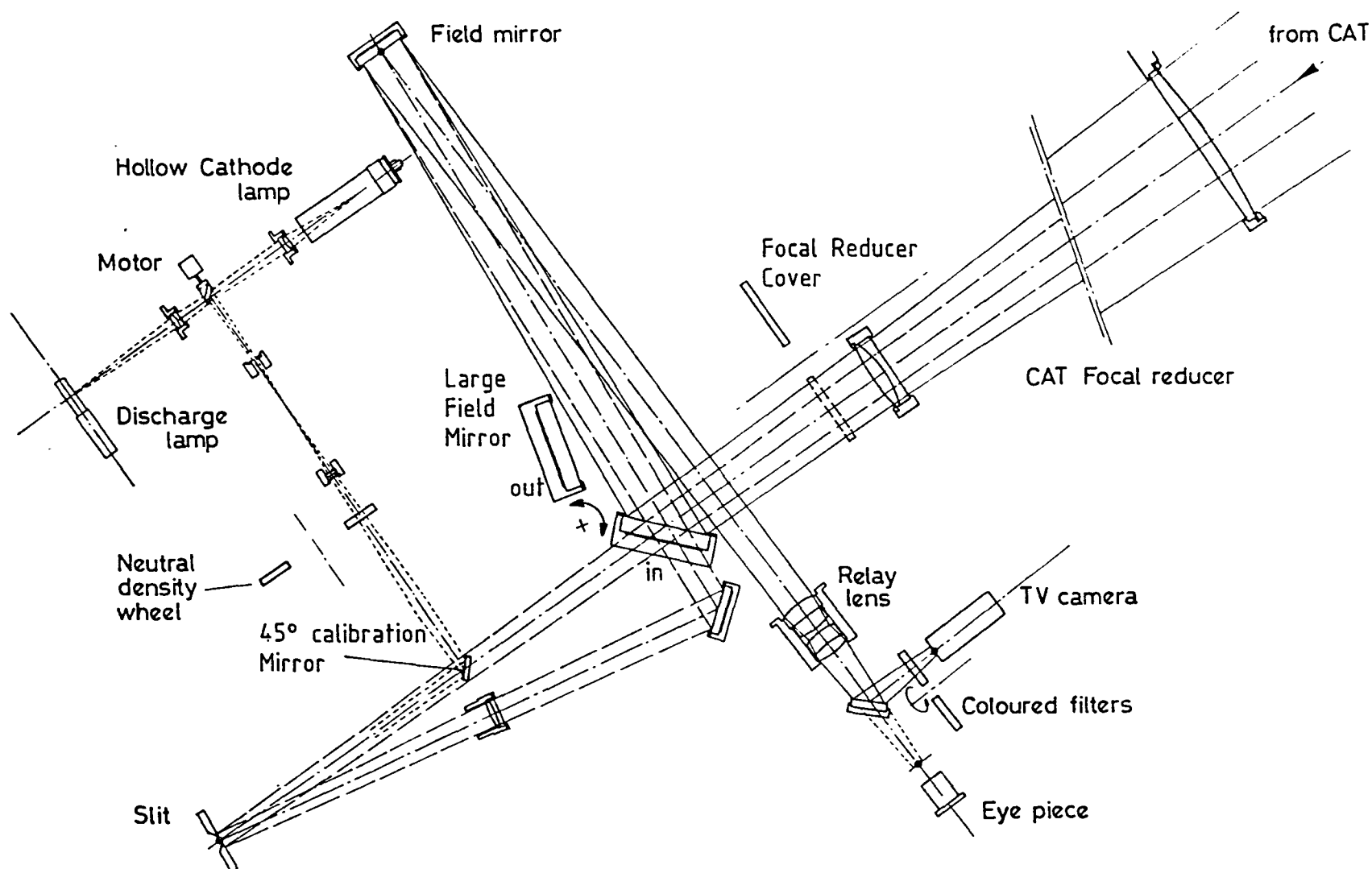


Figure 2.5: Optical schematic of the slit environment

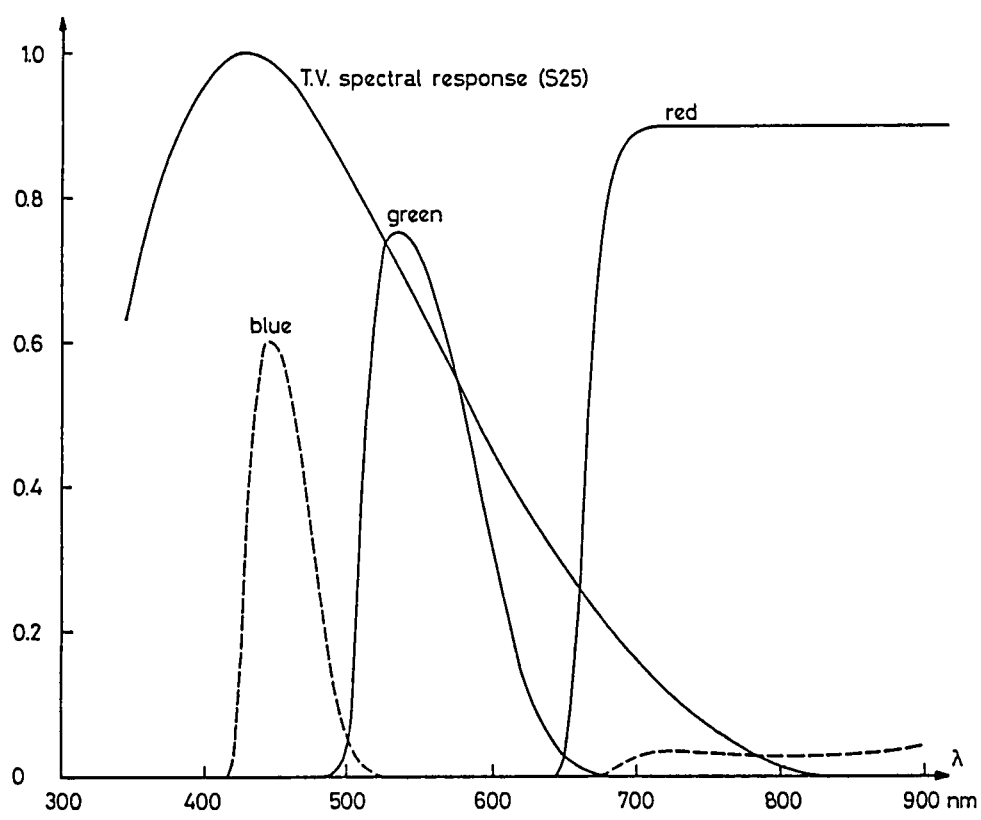


Figure 2.6: Spectral response of slit view TV camera and transmission curves of slit view filters.

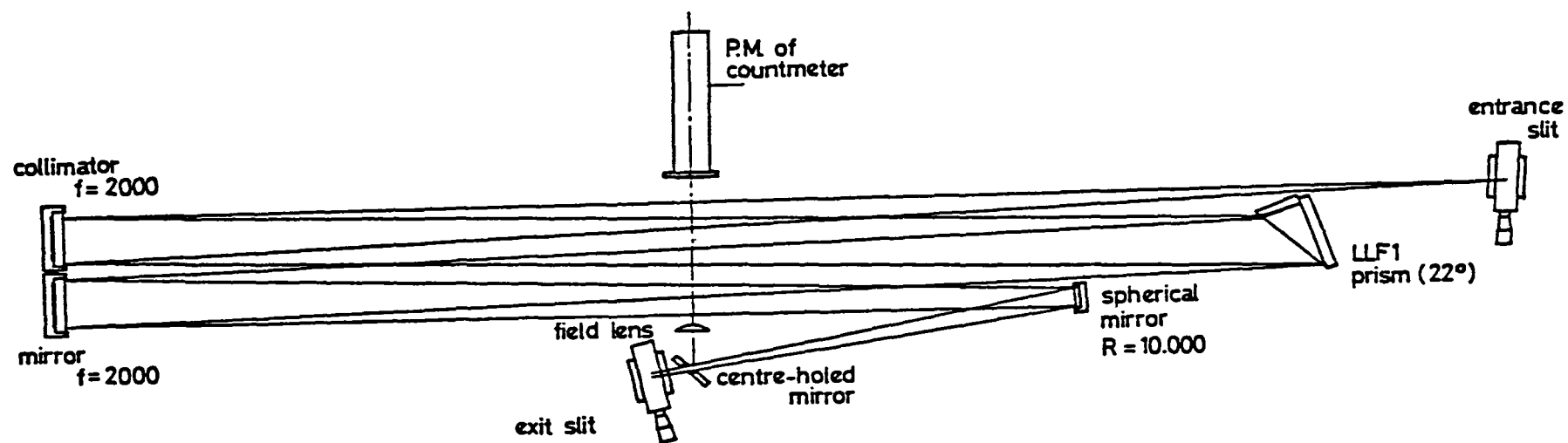


Figure 2.7: Optical arrangement of predisperser

The dispersions are 0.18 \AA/mm and 0.42 \AA/mm at 4000 \AA and 9000 \AA respectively.

The resolving power may be chosen in the range $30.000 - 150.000$. A real-time display of the accumulated spectrum is shown on a graphics terminal.

2.4.3 The double pass scanner

The single pass beam may be deviated towards the double pass intermediate slit area by a small tilt of the camera mirror around a horizontal axis. As usual, all optical elements are doubled. A small total reflection prism sends the light through the intermediate slit to a second prism which in turn reflects the beam once more towards the collimator. Finally, the light is diffracted a second time by the grating and imaged on the exit slit by the camera mirror.

The selection between the paths are made by tilting the camera mirror either slightly upwards or downwards. Thus, the red and blue path beam axis are symmetrically placed with respect to the horizontal Czerny-Turner plane.

The intermediate slit removes all grating ghosts as well as scattered light outside the profile proper. The result is a very pure instrument profile with which it is possible to reach resolutions as high as 210.000 with a linear dispersion half that of the single pass scanner.

Due to the added number of optical elements, the efficiency of the double pass is low, restricting its use to very bright stars.

The operation of the double pass mode is very similar to the single pass. The only additional parameter to set is the width of the intermediate slit. In practice this is chosen as a compromise between the degree of filtering and instrument efficiency.

2.4.4 The Maksutov Long Camera mode

The Long Camera (Fig. 2.10) is a Maksutov system with a Newtonian focus. It has an aperture of $f/4.7$, a focal length of 942 mm and a reciprocal linear dispersion of 1.45 \AA/mm at 5000 \AA . Two pillars located between the grating and the scanner camera mirror carry the camera (Figs. 2.3 and 2.4). It is held in a fixed position by three isostatic supports from which it can easily be lifted off to allow the CES to work in the scanner mode or with the short camera. No optical elements have to be removed or changed during the change over. The detector with its dewar and controlling electronics is mounted below the camera. A three-point attachment allows orientation and focusing of the detector.

In the Long Camera mode the grating remains in a fixed position. The detector is either a reticon array or a CCD. The reticon array has 1872 pixels of size $15 \times 700 \mu\text{m}$. It covers a wavelength range of 41 \AA at 5000 \AA (Tab. 1). Resolving powers used with the Long Camera lie normally between 70.000 and 110.000 .

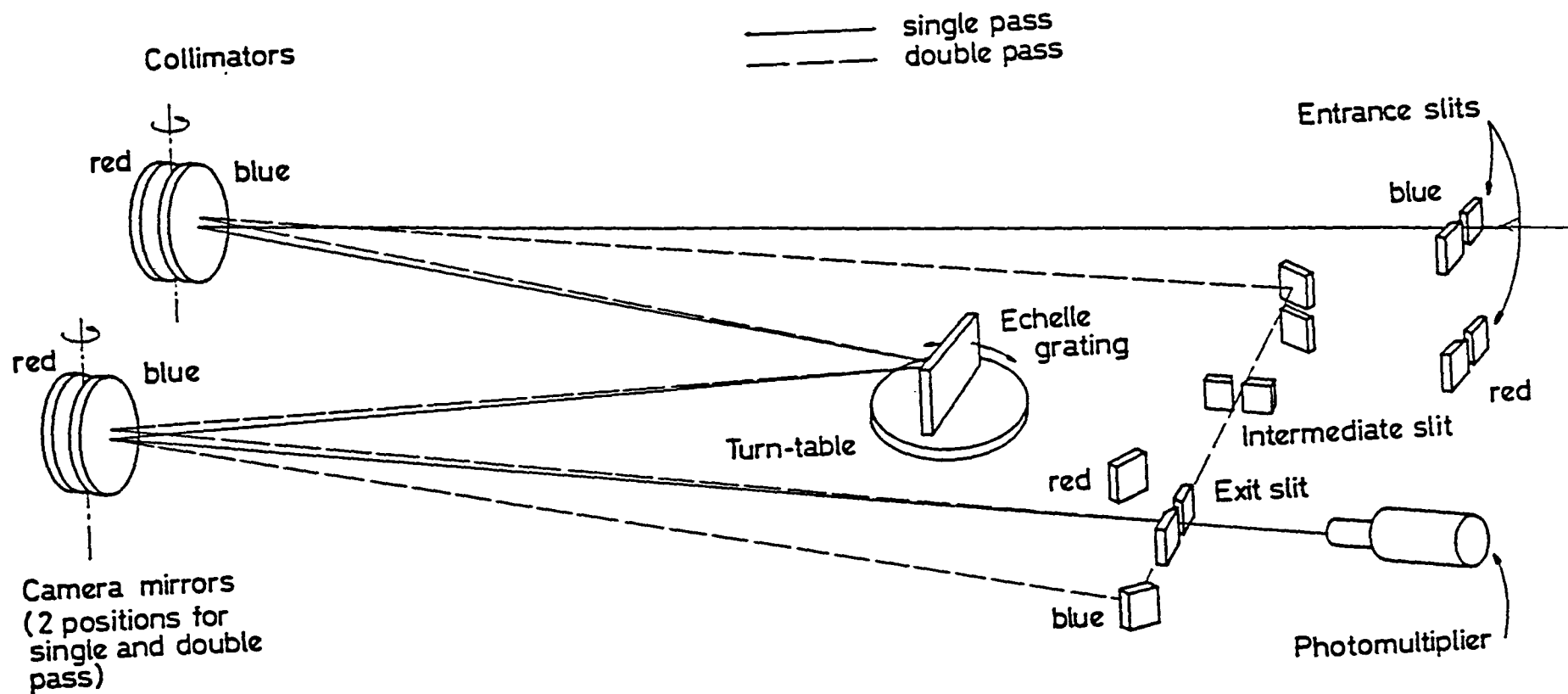


Figure 2.8: Scanning mode of the CES

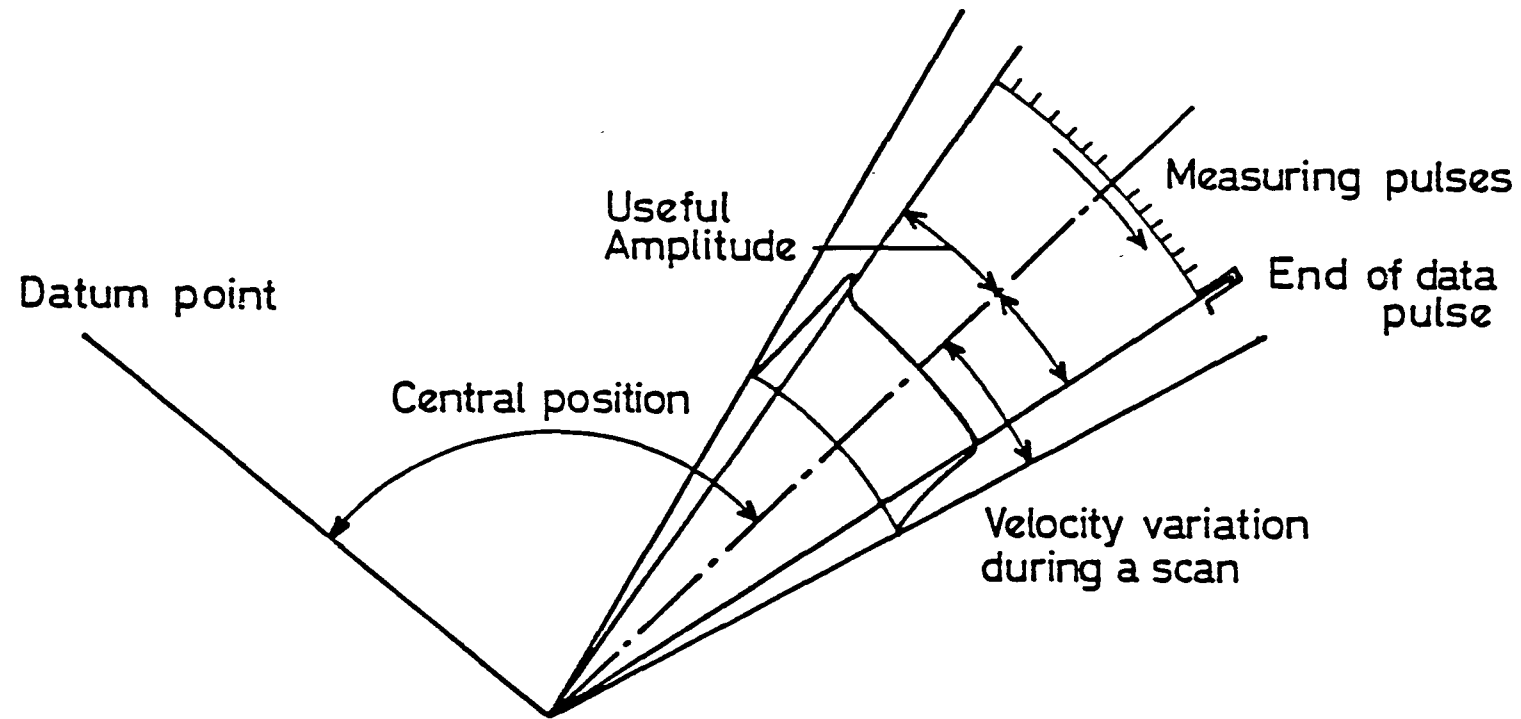


Figure 2.9: Grating turn-table operating principle

An RCA high resolution CCD (currently ESO #9) with 640×1024 pixels is also available as detector. The pixel size is $15 \times 15 \mu\text{m}$ corresponding to $0''.56$ and $0''.45$ in the dispersion and slit directions respectively. As compared with the reticon the CCD is substantially more efficient but the wavelength coverage is only half that of the reticon. Towards redder wavelengths interference fringes in the CCD cause problems.

The operation of both the reticon and the CCD are fully controlled from the MULTI program. IHAP with a RAMTEK and a graphics terminal is available for data analysis.

2.4.5 The Short Camera mode

A second, faster, $f/1.8$ dioptric camera is available since 1986 [3],[15]. It was designed to be compatible with the properties of the high resolution CCDs. CCD #9 is used also with this camera.

Fig. 2.11 (adapted from ref [14]) shows the camera together with the CCD assembly. The position of the support carrying the CCD dewar can be adjusted to allow alignment and focusing. A movable focusing lens controlled from the MULTI program assures correct focus setting at all wavelengths. The focal length of the camera is 516.5 mm and the reciprocal linear dispersion 2.6 \AA/mm at 5000 \AA . The spectral range covered by the CCD in one exposure is around 40 \AA (Tab. 1). Reasonable resolving powers lie between 30.000 and 60.000 (see Tab. 3). The upper limit is approximately defined by the Nyquist criterion of two pixels per spectral resolution element. The $15 \times 15 \mu\text{m}$ pixel size corresponds to $0''.83$ and $1''.02$ in the slit and dispersion directions respectively.

2.5 Detectors

2.5.1 The scanner photomultiplier

The tube used in the scanner modes is an RCA Quantacon, model 31034 A, operated at 2000 V. It has a gallium-arsenide photocathode and an UV transparent window. It is Peltier cooled to -40°C where the dark noise is around 5 c/s. The responsivity and quantum efficiency curves are given in Fig. 2.12.

2.5.2 The CCD

The CCD currently used with both the long and short cameras is the ESO #9. All the characteristics of this chip are given in Fig. 2.13 together with the quantum efficiency curve [11]. Interference fringes occur at all wavelengths but reach severe amplitudes only above $\sim 6500 \text{ \AA}$. For wavelengths shorter than this, the fringes can normally be removed by proper flat fielding. From the MULTI program it is possible to select the working area as well as the binning factors

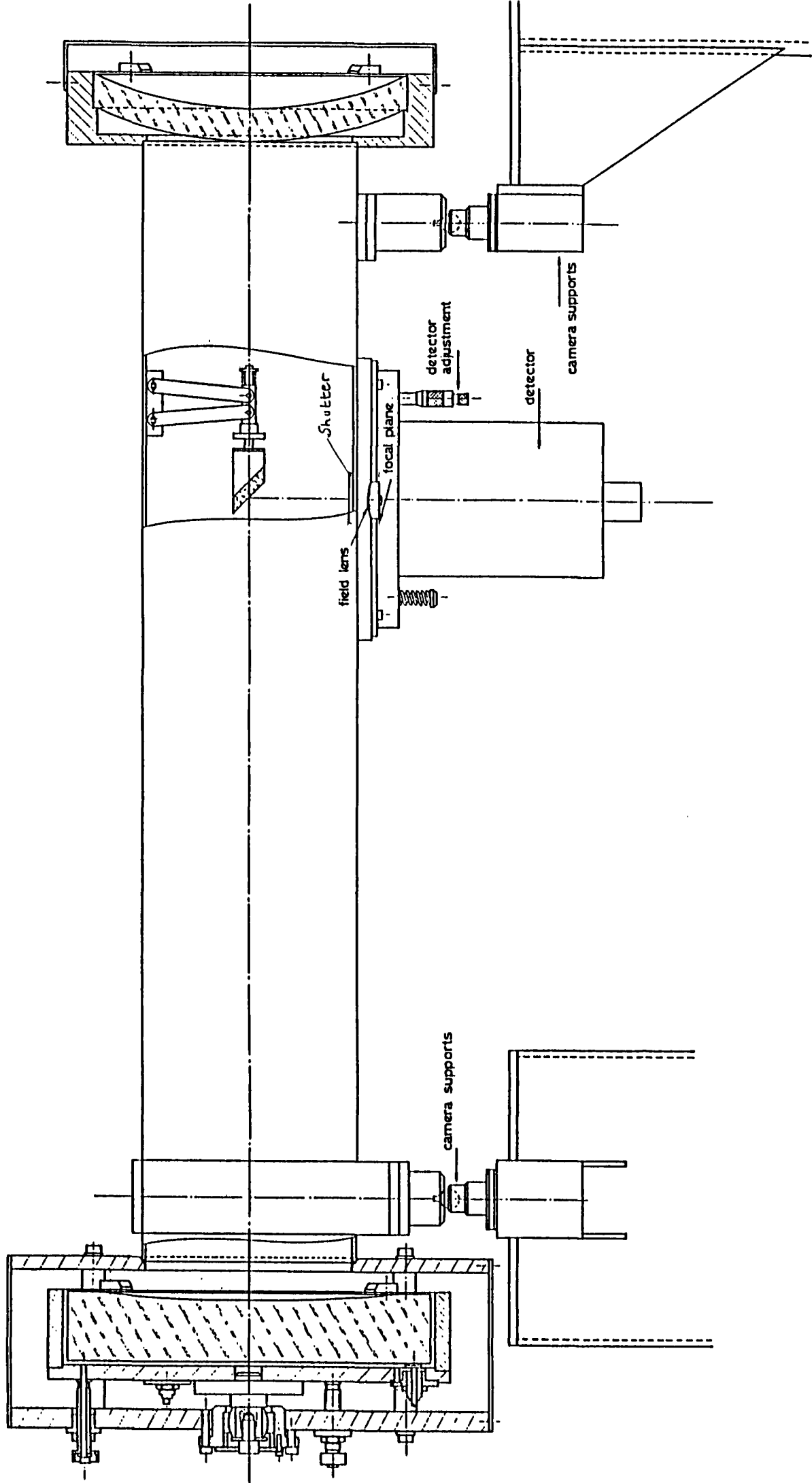


Figure 2.10: The Long Camera

Table 2.1: Spectral Coverage of the CES

Order	Wavelength			Spectrum length λ					
	Min	Blaze	Max	Short cam. + CCD			Long cam. + CCD		Long cam. + Reticon
65	3459.0	3479.3	3512.9	28.3	27.8	26.8	15.5	15.2	14.7
64	3513.0	3533.7	3567.9	28.8	28.2	27.2	15.8	15.5	14.9
63	3568.0	3589.8	3624.9	29.3	28.7	27.6	16.0	15.7	15.2
62	3625.0	3647.7	3682.9	29.7	29.1	28.1	16.3	16.0	15.4
61	3683.0	3707.4	3741.9	30.3	29.6	28.6	16.6	16.2	15.7
60	3742.0	3769.2	3806.9	30.8	30.1	29.0	16.9	16.5	15.9
59	3807.0	3833.1	3871.9	31.3	30.6	29.5	17.2	16.8	16.2
58	3872.0	3899.2	3938.9	31.9	31.1	30.0	17.5	17.2	16.4
57	3939.0	3967.6	4008.9	32.5	31.7	30.5	17.8	17.4	16.7
56	4009.0	4038.5	4080.9	33.1	32.2	31.0	18.1	17.7	17.0
55	4081.0	4111.9	4154.9	33.7	32.8	31.6	18.5	18.0	17.3
54	4155.0	4188.0	4231.9	34.3	33.4	32.2	18.8	18.3	17.6
53	4232.0	4267.1	4312.9	35.0	34.1	32.7	19.2	18.7	17.9
52	4313.0	4349.1	4396.9	35.7	34.7	33.3	19.6	19.0	18.3
51	4397.0	4434.4	4483.9	36.4	35.4	34.0	20.0	19.4	18.6
50	4484.0	4523.1	4572.9	37.2	36.1	34.7	20.4	19.8	19.0
49	4573.0	4615.4	4666.9	38.0	36.8	35.3	20.8	20.2	19.4
48	4667.0	4711.5	4765.9	38.8	37.6	36.0	21.3	20.6	19.8
47	4766.0	4811.8	4867.9	39.7	38.4	36.8	21.8	21.1	20.2
46	4868.0	4916.4	4973.9	40.6	39.2	37.6	22.3	21.5	20.6
45	4974.0	5025.7	5084.9	41.5	40.1	38.4	22.8	22.0	21.0
44	5085.0	5139.9	5201.9	42.5	41.0	39.2	23.3	22.5	21.5
43	5202.0	5259.4	5324.9	43.6	42.0	40.1	23.9	23.0	22.0
42	5325.0	5384.6	5452.9	44.6	43.0	41.0	24.5	23.6	22.5
41	5453.0	5516.0	5587.9	45.8	44.0	41.9	25.1	24.1	23.0
40	5588.0	5653.9	5727.9	46.9	45.1	43.0	25.7	24.7	23.6
39	5728.0	5798.8	5875.9	48.2	46.3	44.0	26.4	25.4	24.1
38	5876.0	5951.4	6031.9	49.6	47.5	45.1	27.2	26.0	24.8
37	6032.0	6112.3	6195.9	51.0	48.8	46.3	28.0	26.8	25.4
36	6196.0	6282.1	6369.9	52.5	50.1	47.6	28.8	27.5	26.1
35	6370.0	6461.6	6557.9	54.1	51.6	48.7	29.7	28.3	26.7
34	6558.0	6651.6	6747.9	55.7	53.1	50.3	30.5	29.1	27.6
33	6748.0	6853.2	6954.9	57.6	54.7	51.7	31.6	30.0	28.4
32	6955.0	7067.3	7173.9	59.5	56.4	53.3	32.6	30.9	29.2
31	7174.0	7295.3	7407.9	61.5	58.7	54.9	33.7	31.9	30.1
30	7408.0	7538.5	7656.9	63.7	60.2	56.7	34.9	33.0	31.1
29	7657.0	7798.4	7924.9	66.1	62.2	58.5	36.2	34.1	32.1
28	7925.0	8076.9	8209.9	68.6	64.5	60.5	37.6	35.4	33.2
27	8210.0	8376.1	8517.9	71.3	66.9	62.7	39.1	36.7	34.4
26	8518.0	8698.2	8849.9	74.3	69.4	64.9	40.7	38.1	35.6
25	8850.0	9046.2	9208.9	77.5	72.2	67.4	42.5	39.6	36.9
24	9209.0	9423.1	9596.9	82.0	75.2	70.0	44.4	41.2	38.4
23	9597.0	9832.8	10019.9	84.8	78.5	72.9	46.5	43.0	40.0
22	100020.0	10279.7	—	89.0	82.1	—	48.8	45.0	—

of the CCD. The full-well capacity of the CCD is of the order of $150.000\text{ e}^-/\text{pix}$. Since 1 ADU is approximately 7.4 e^- , the upper limit of 16384 ADUs set by the A/D converter corresponds to $\sim 120.000\text{ e}^-/\text{pix}$. The CCD should not be used at values close to this limit.

2.5.3 The Reticon

The reticon is a self-scanned linear photodiode array of 1872 elements. Each diode has a size of $15 \times 700\text{ }\mu\text{m}$, giving a total length of 28 mm. It is housed in a liquid nitrogen cryostat and maintained at a temperature of approximately 132°K . By increasing the temperature $10^\circ - 20^\circ$, an increase in sensitivity may be achieved in the red. At the same time the noise will increase. It remains to be established at what temperature (as a function of wavelength) the S/N ratio is maximized.

The readout noise is around $1000\text{e}^-/\text{pix}$. 1 ADU corresponds to approximately 1300e^- . The dark current is between 5 to 10 ADU/hour, but may be substantially higher for 1–2 hours after the reticon has been illuminated with strong light. Thus, flat fields or wavelength calibrations should not be done immediately before long stellar exposures. The first and last 40 pixels are not illuminated to serve as a check of the internal dark level. The relative response curve is shown in Fig. 2.14 The maximum value corresponds to approximately 70 % quantum efficiency. The full-well capacity of the reticon is substantially higher (the exact value has not yet been determined) than that for the CCD, resulting in a higher signal resolution. This makes the reticon a better detector choice if one aims at the very highest S/N ratios for *bright* objects. Very approximately, the limit in magnitude falls around $V = 5.0$. Due to the absence of interference fringes in the red and near infrared regions, one should consider using the reticon at these wavelengths also for somewhat fainter stars. The upper signal limit of 4095 ADUs is set by the A/D converter. This limit is somewhat below the full-well capacity, to ensure the linearity of the reticon at high signal levels.

2.6 Software

A complete description of the CES software can be found in reference [8].

Two different programs have been written for the CES: MULTI for the long and short cameras, and SCAN for the scanner. Their corresponding detector control parts are PHOTO (for SCAN) and CCD or RETIC (for MULTI). The two latter routines set up the CCD and reticon electronics, execute exposures, and store the result on disk and tape. The GRAPH routine can be used for a fast and semi-automatic preliminary reduction of reticon or scanner data. This routine is meant to be an on-line facility only; the results cannot be saved. However, IHAP is always available for all types of image processing.

The observer interacts with all control programs mainly via an extended set of softkey menus. The detailed use of these is illustrated in the next chapter.

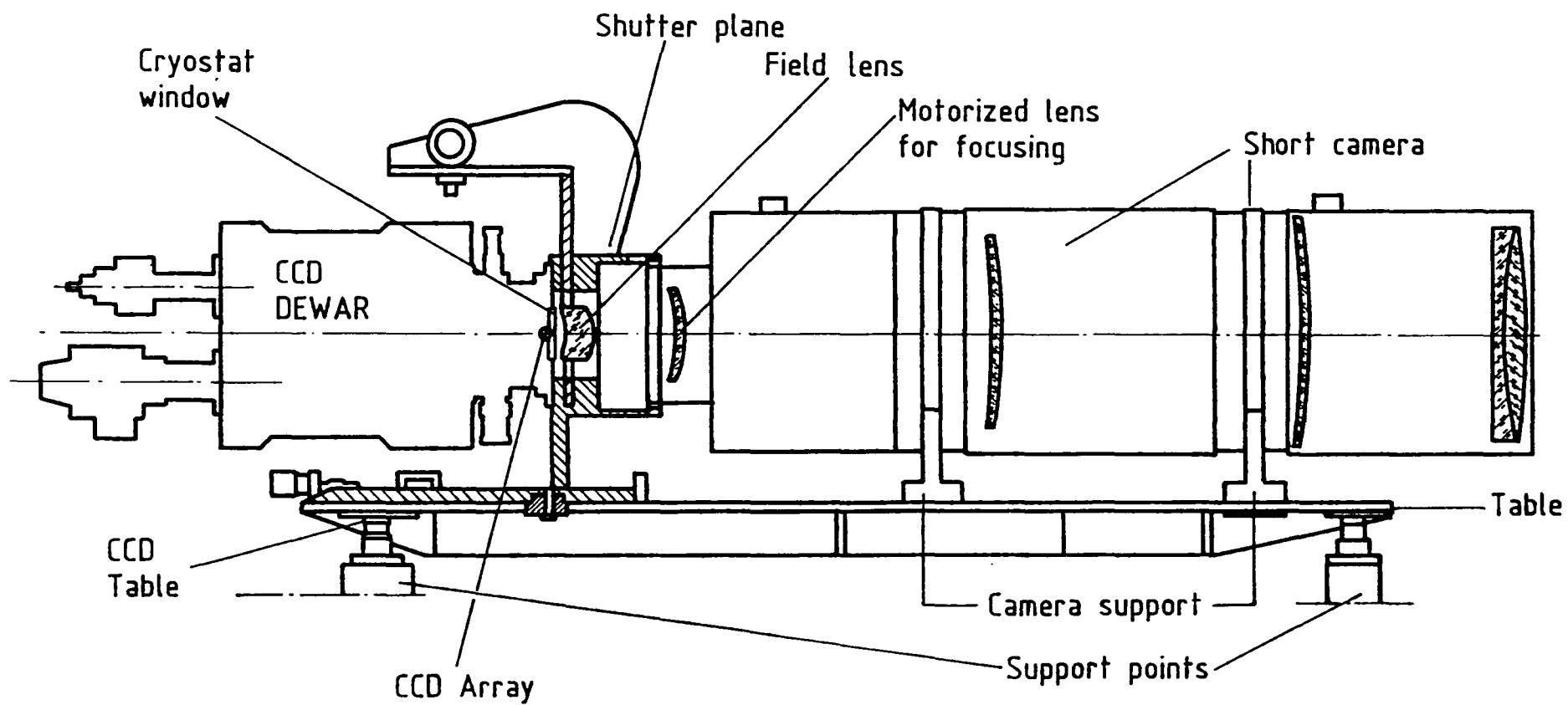


Figure 2.11: The Short Camera

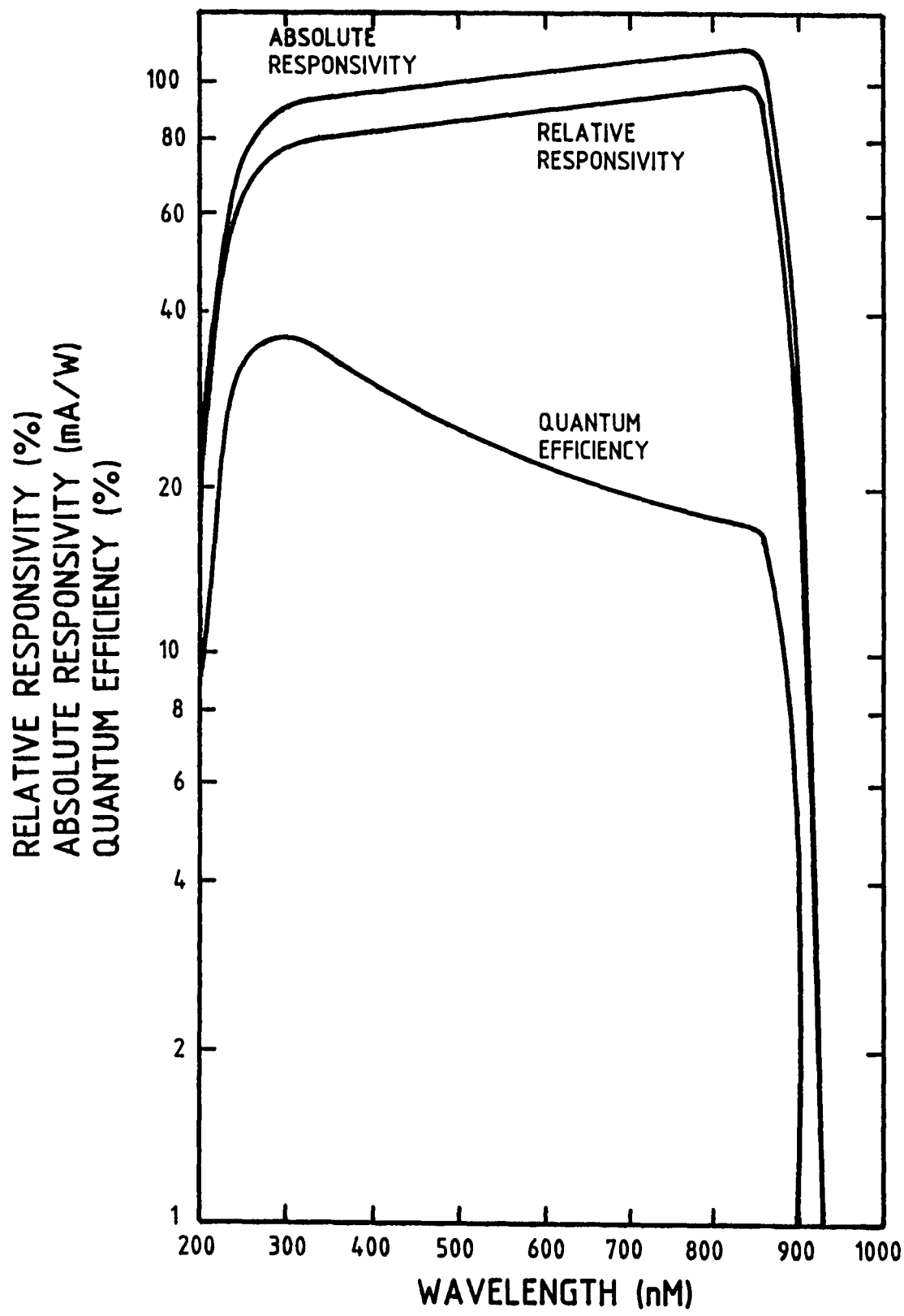


Figure 2.12: Responsivity and Quantum Efficiency of the Quantacon Tube.

CCD # 9

Type: RCA SID 503 High Resolution, thinned, backside illuminated.

Serial number: 5103-15-5

Format: 1024 × 640 pixels

Pixel size: 15 × 15 microns

Image size: 15.6 × 9.8 mm

Conversion factor: Normally used at G50 i.e. $7.4 \text{ e}^-/\text{ADU}$.

Noise level: Approx. 33 e^- at Gain 50 at Fast readout.

Linearity: To be measured. CCD saturation is about $150.000 \text{ e}^-/\text{pix}$.

Blemishes: There is a bad column at X480. There are many columns pairs with small negative/positive offsets. Every 17th row has lower sensitivity.

Dark current: Very low. Less than $2.5 \text{ e}^-/\text{pix}/\text{hr}$.

Charge transfer: Very good in both directions. No preflash is required.

R.Q.E.: Measured at 140 K. See fig. below.

Operating temp.: 140 Kelvin.

22

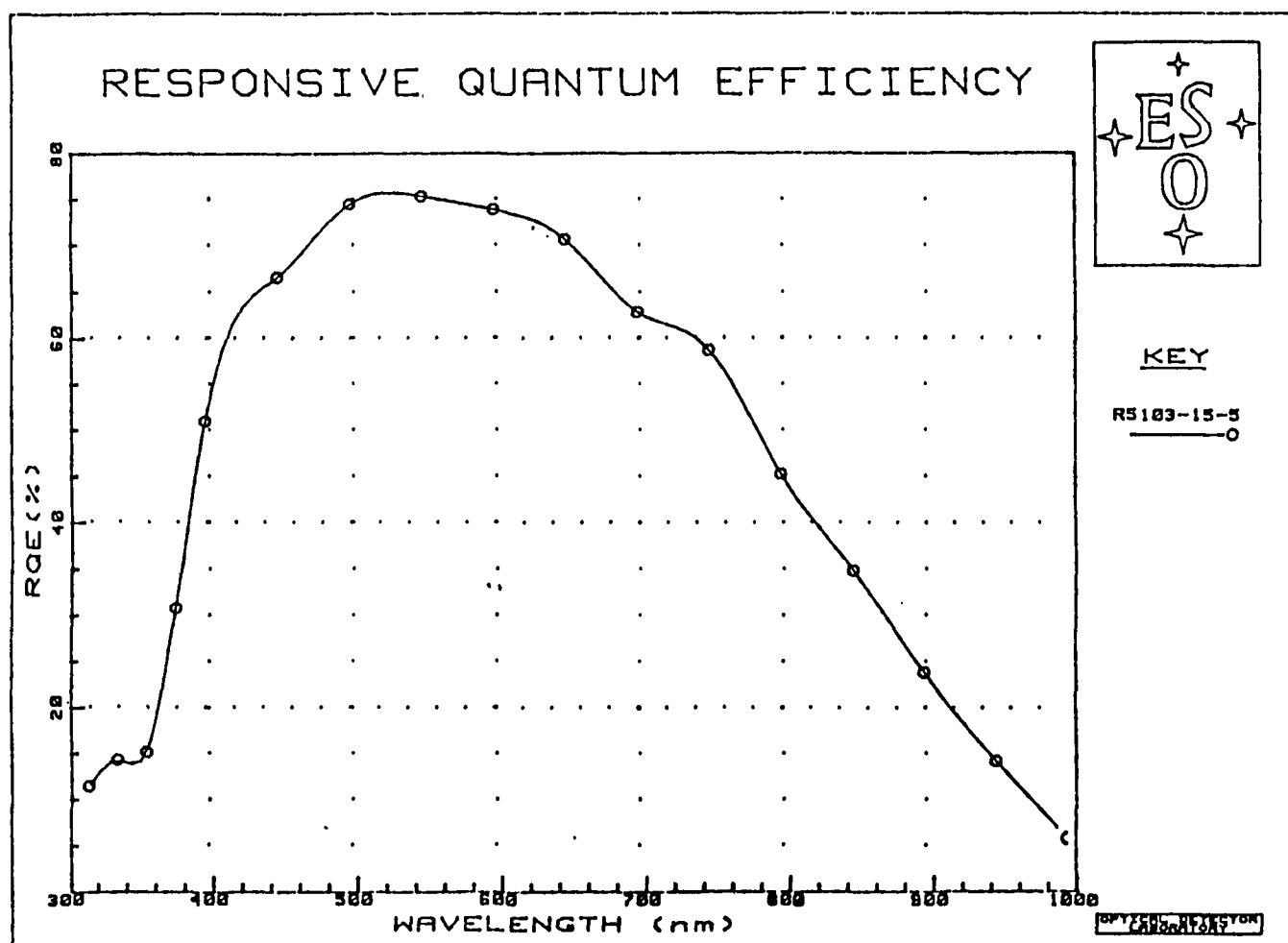


Figure 2.13. CCD # 9 Features

For final reductions of CES data, reference is also made to the relevant parts of the MIDAS Users Guide [16].

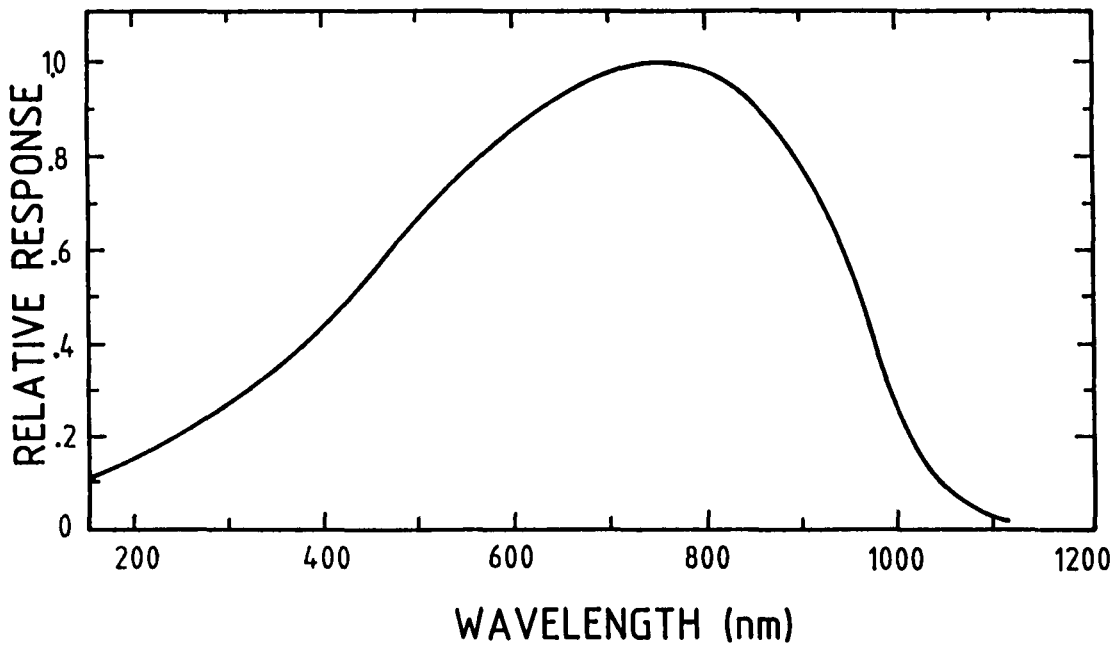


Figure 2.14: Relative Response Curve of the Reticon.

Chapter 3

CES Operating Procedure

3.1 Introduction

A detailed step by step description of the handling of the long camera and the reticon is given in section 3.2. As the operation of the CCD on the long or short camera is very similar to the reticon procedure, only the differences which are not obvious are described in section 3.3.

3.2 The Long Camera Reticon mode

3.2.1 Starting up

In the spectrograph room:

- Remove cover from collimator. It is magnetically attached to the mirror support.
- Remove the grating cover *very carefully*. No fingerprints or scratches please! Hold the cover with one hand and loose the four corner screws with the other. Gently lift off the cover. Be very careful with the Hartmann screens which may fall open very easily.
- Remove cover from Maksutov camera.
- Check that the viewing microscope is in its lowest position and does not obscure the camera.
- Check that all dust-covers protecting the predisperser, the intermediate slit area, and the scanner photomultiplier are in place and properly fastened. If not, ask the Operations Group for assistance.
- Check that the liquid nitrogen bottle has enough nitrogen to last the night (normally done by the technical crew during daytime). A meter is mounted on the outlet tube.

- Check the pressure inside the dewar. If the gauge has been switched on at the end of the previous night the pressure should not be higher than 2×10^{-5} mbar (scale 2). If the gauge has just been turned on, the reading should not exceed 10^{-3} mbar (scale 1).
- Switch off the reticon dewar pressure gauge control. This is important since the meter produces an optical glow which otherwise will be added to the signal.
- Reset Reticon controller. Small black push-button to the left of the red controller power switch.
- Go to the double doors at the end of the Coudé room and turn off the lights in the corridor outside. Lock the doors.
- Turn off the lights in the spectrograph room and check that no light is visible anywhere. Pay special attention to small control lamps on electronic equipment and to possible leaks from the computer corridor.
- Check that the CRT-display screen of the reticon controller is switched off. The cover in front of the screen is not sufficient to prevent stray light!
- Check that the door between the Coudé room and the slit room is properly closed.

In the slit room:

- Check that all predisperser dust-covers are in place.
- Open the cover in front of the focal reducer. If you are doing calibrations during daytime, leave it closed to prevent daylight entering from the CAT dome.
- Check that the lever of the TV mirror is pushed in to send the light to the TV viewing system. Select your filter in front of the TV camera (normally white for objects at lower airmass). Do not use the red filter with the blue path or the blue with the red! You will have problems with atmospheric differential dispersion during autoguiding if you do.
- Switch off the light and check that no lights are visible from control lamps or leaking in from outside the slit room.
- Close the door between the slit room and the control room carefully.

In the control room:

- The nitrogen refilling of the dewar is automatic, but you must check that on the black control box on top of the racks the blue "AUTO" light is on. You can fill the dewar at any moment by pressing this blue "AUTO" switch. The yellow "VALVE OPEN" light will then go on to show that the refilling has started. When it has finished the "AUTO" light will again switch on. Normally you may leave the refilling in the automatic mode, the dewar will then fill up every third hour. A short alarm will inform you. This alarm should stop after a while.

- The three red warning lamps (“FAULT”, “AIR FAIL” and “DATUM LOST”) on the grating-table control rack should be off to indicate that the table is in operational status. If one of these is on, the reason may be that the table air pressure is, or temporarily was, too low. Check that the table is on line: “ON LINE” button should be lit. If not, press it.
- Mount the appropriate magnetic tape, one for each night of the week. Remember the write-ring. Leave the drive “ON LINE” with “SELECT CODE” 0.
- Check that the HP printer/plotter and the Epson printer are switched on and are on line. These units can be left on during daytime. A log of all activities during the night will automatically be written on the Epson printer. If you plan to use the IHAP turn on the HP pen-plotter.
- Turn off the lights in the computer corridor and in the stairs leading to the control room.
- Dim the lights in the control room.

3.2.2 Calibration exposures

Hit any key on the main terminal to get the RTE-prompt `USERNAME?`. Type `MULTI`. The program starts.

Follow the instructions written by `MULTI`, in particular the check of the computer Universal Time.

The `MULTI` program modules are loaded.

Answer the question `Initialize CAMAC modules?` with `YE`.

The `MULTI` program checks the functioning of the remotely controlled moving parts of the spectrograph. No time-out error messages should occur during these tests.

If no other errors are encountered by the `MULTI` program the first menu will appear:

OBSERVATION	MOTORS	ENGINEERING	HELP
Status	Restore sts screen	Function disabling	TERMINATE

On the left screen will be displayed the optical parameters of the CES. The values for the predisperser, the slit and the grating table position are those found at the end of a CAMAC initialization. The other optical parameters are set to zero. Also given in the form are several temperature readings as well as the light-path status of the focal reducer and the collimators. Check that these optical elements are either all “BLUE” or all “RED” according to the value

of your central wavelength. (This will also be done automatically by the MULTI once the wavelength has been entered). If the MULTI is started without a CAMAC initialization, the values in form # 2 will be those which were used in the previous run.

Press **MOTORS** and a new menu will appear:

Move decker	Open shutter		Help
	Close shutter	Function disabling	PREVIOUS MENU

In this menu hit **Move decker**. Form # 38 will be displayed. Choose your slit-height, for the reticon normally around 5". Press "ENTER" and check on the left screen that it has been accepted.

In any form you can exit by softkey **f1** if you do not want any action to be taken. You can move the terminal cursor by the arrowed keys or by the "TAB"-key in which case you move it to the next white input field. "CTRL-TAB" moves it back to the previous field.

Press **PREVIOUS MENU** to come back to the observation menu.

Press **STATUS**. The temperature control should be set to 130–135 K and the actual temperature must be within two degrees of this value. Also displayed is a measure of the relative voltages of video lines 2, 3, and 4 with respect to line 1. This is done by calculating the mean value of every 4th reticon pixel in the previous exposure and taking the ratios of these means. In order for these values to be meaningful, the exposure has to be reasonable flat, i.e. The calibrations should not be used for this check. The ratios of these offsets should lie between 0.95 and 1.05. If not, a four pixel periodic pattern may be introduced in all exposures which may not be fully removed after division by the flat field.

Press **OBSERVATION** to enter the following menu:

Define single exp.	--- ETC ---	End of object	Help
Start single exp.	GRAPHICS	IHAP	PREVIOUS MENU

Then **Define single exp.**. The define exposure menu will appear. On the left screen will be displayed the calibrations lamps and the neutral density filters used in front of these lamps (form # 13). These filters are not situated in the main light-path of the CAT – CES:

* COUDE ECHELLE SPECTROMETER * Multichannel instrument setting help * Form# 13 *

Calibration lamp (only valid if exposure type is 'CL'):

#1	#2	#3	#4	#5	#6	#7	#8
h.c.Fe	h.c.Th	Hg	Ne	None	White	Laser	None

Neutral density filter:

	#1	#2	#3	#4	#5	#6	#7	#8
- blue:	zero	1.89	2.97	3.44	zero	0.49	0.98	1.61
- red:	zero	1.87	3.01	3.97	zero	0.45	0.99	1.58

Extensive help on the 'SINGLE EXPOSURE DEFINITION' form is available.
Use the 'HELP' softkey!

First define a regular exposure to get a display of the appropriate optical parameters:

EXPOSURE DEFINITION

Type RE (REgular, Flat Field, DarK current, CaLibration)
Exposure time 0. 2. 0 h.mm.ss (for ex.) Tape recording 0 (0=off,
Identifier Test only (test only, don't save) 1=IHAP format)
Batch file -----(Ignore) Number of exposures 1 (1-99)

INSTRUMENT SETTING 1 (0=No, 1=Yes)

Calibration lamp# - (Ignore) Neutral density filter - (Ignore)
Central wavelength (2800-12000) 5893.00 Angstroms (or your own choice)
Spectral resolution (0-1000) ----.0 milli-Angstroms (Ignore)
or resolving power (0-100000) 100000. (or your own choice)
or entrance slit width (50-5000) ----. microns (Ignore)
or image slicer (Y/N) ? - (Ignore)

TELESCOPE SETTING 0 (0=No, 1=Preset)

Right ascension --:--:--.- Declination ---:--:--.- (Ignore)

Press ENTER key to proceed (or softkey #1 to abort).

You may choose to define the spectral resolution or the entrance slit width instead of the resolving power. Corresponding parameters will be calculated by the MULTI program. Telescope coordinates are automatically read from the CAT control program.

Press the ENTER key. The instrument setting will now appear on the left screen with all the chosen and calculated instrument parameters (Form # 02). Check that the grating angle is identical with the one displayed on the turntable control rack.

* COUDE ECHELLE SPECTROMETER * Multichannel instrument status * Form# 02 *

Pre-disperser prism position 26953. encoder units in RED path; ENabled

Decker height 5.00 arcseconds

Entrance s

lit width 244. microns

Pre-disperser exit s

lit width 1252. microns

Grating position 275:53: 9.4

Focal reducer front element RED

Temperature turntable in 17.6

Focal reducer back element RED

Temperature turntable out 16.9

Predisperser collimator RED

Temperature Coude room 15.8

Main collimator RED

Temperature s

lit room 18.8

Temperature dome 19.3

Calibration lamp undef.-

Neutral density filter 3.01

Central wavelength 5893.00 Angstrom

Grating order 38.

Spectrum length 50.28 Angstrom

Grating efficiency xx % of max

Incidence angle 65.1743 degrees

Predispersion 98.9 A/mm

Diffraction angle 59.4843 degrees

Linear dispersion 1.80 A/mm

Spectral resolution 58.9 mAngstrom

Free spectral range 151.1 Angstrom

Resolving power 100000.

Projected entr s

lit xx.x microns

The predisperser is a small prism spectrograph which preselects a narrow wavelength range centered around the wavelength you have chosen. Typically this range is ~ 3 times larger than that registered by the reticon. In this way very little light with wavelengths outside the range under investigation will enter the main spectrograph and cause scattered light. In our example the spectrum length on the reticon is 50.28 Å and the free spectral range defined by the exit slit of the predisperser is 151.1 Å. With a spectrum length of 50.28 Å and 1872 reticon elements the dispersion is 26.9 mÅ/pixel, which is approximately half of the spectral resolution element. Thus, undersampling starts at a requested resolving power higher than $\sim 110,000$ (at a central wavelength of 5893 Å).

Readout signal

Let us now do a short dark exposure (= readout signal). Again press Define single exp. to enter the exposure definition menu:

Type	DK
Exposure time	2 sec
Tape recording	0
Identifier	READOUT 2 sec
No. of exposures	1

Since a DK-exposure will not set or change anything in the spectrograph, the other parameters are not relevant.

Press "ENTER" and then **Start single exp.**. Wait until the exposure is finished.

Go into the **GRAPHICS** menu:

RAW-graph	OBJECT-graph	DARK-graph	Help
FLAT FIELD-graph	CALIBRATED-graph	--- ETC ---	TERMINATE

Since the exposure was defined as DK it will be the currently active dark used by MULTI and GRAPH for on-line reductions. Pressing **DARK-graph** will display it on the left screen. The Y-axis is in arbitrary units from 0 to 4095. 1 unit corresponds to approximately $1300e^-$. The readout signal must nowhere reach zero! The (upper) X-axis is in reticon channel numbers. The wavelength scale is undefined for dark exposures.

At the end of an integration every exposure is written into the IHAP working area on the disk. This working area is always the IHAP file No. 1. A file may consist of one or several scanlines where one scanline is one exposure. A file is closed by the **End of object** softkey. When this key is pressed the content of IHAP file 1 is copied to a file at the end of the IHAP file stack. It is also written to tape if the "Tape Recording" was set to 1 during the last exposure definition. If for some reason you do not wish to keep the exposure(s) you have made since the last **End of object** you can find a **Cancel object** key in the menu which will appear if you press **--- ETC ---**:

Log graph screen	Define sequence	Special setting	Help
Cancel object	Start sequence	Function disabling	PREVIOUS MENU

Press **Cancel object** twice. Return by **PREVIOUS MENU**.

Cancel in this way the dark exposure you just made. Go back to **Define single exp.**. Keep previous settings except for **Number of exposures** which you now set to, for example, 5. The **Tape recording** and the **Number of exposures** return to 1 automatically every time you enter **Define single exp.**. Start the series of exposures with **Start single exp.**. Answer the ready-question with YES. Wait until finished.

Hit **End of object**. A file of 5 scanlines is now saved on tape and on disk. The last scanline (exposure) will be the new active dark. Press **IHAP** to reach the first IHAP menu:

TRANSVERSE	OVERTRACE	SAMPLE	--- ETC ---
DLIST,AL	CUT	COORDINATES	TERMINATE

Then **DLIST,AL** to see the file in the IHAP working directory. Exit IHAP by **TERMINATE**.

These short darks will now serve as readout signals which have to be subtracted from all subsequent exposures. A series of readouts is also useful to, at least to some extent, "clean" the reticon from remnant charge after it has been exposed to strong light such as flat field lamps, thorium lines, very bright stars, etc. You should repeat the readouts several times during the night since they are not absolutely stable with time. Each readout signal furthermore contains a small component of noise. This noise is of course reduced by taking the mean of the five exposures. Remember that the reticon cannot be completely "cleaned" after illumination by strong light. Saturation creates electron-hole pairs also in regions of the diode (mainly the surface) that cannot be read out. These will slowly drift into the main part of the diode causing a remnant signal. As mentioned before, the only way to completely get rid of these is to wait 1 - 2 hours before the final readout. Since this is not practical during the night, the observations should be planned with this in mind.

Predisperser position check

The encoder of the predisperser prism is not functioning properly. As a result the actual position has to be checked. In order to see the central wavelength of the region defined by the predisperser, the entrance slit of the CES and the exit slit of the predisperser should be closed down to $\sim 50 \mu\text{m}$. This produces a sharp intensity peak which should be centered at the working wavelength. The procedure to do this is the following:

Press **Define single exp.**

EXPOSURE DEFINITION

```

Type          FF          (for internal flat field lamp)
Exposure time  5 sec      Tape recording 0 (test only)

Identifier     TEST OF PREDISP.
Batch file     (Ignore)   Number of exposures  1
INSTRUMENT SETTING  1
Calibration lamp# 6      Neutral density filter 1 (no filt)

```

Wavelength and resolving power are of course not changed. Press "ENTER"

Now go into the menu under `--- ETC ---` and press `Special setting`. The first try should be made at the predisperser setting chosen by MULTI. Change the entrance slit width of the CES and the exit slit of the predisperser to 50 μm each. Leave the other parameters unchanged:

* COUDE ECHELLE SPECTROMETER * Multichannel special setting* Form# 07 *

```

Predisperser prism position 26070. encoder steps; ENabled
Entrance slit width         50. microns (50-5000)
Pre-disperser exit slit width 50. microns (50-5000)
Decker height 5.00 arcseconds (0.70 - 21.30)
Calibration lamp# 2         Neutral density filter 1
Grating order . (0-76) or grating position 275:12:22.3
Exposure time 0. 1. 0 h.mm.ss

```

Press ENTER key to proceed (or softkey #1 to abort)

Do "ENTER" and wait for the slits to close to 50 μm . MULTI will return by itself to the `Define single exp.` menu. If you escape with `f1` or an error is found in form #7, MULTI will stay in the `Special setting` menu.

Up on the left-most instrument rack are situated two rows of control lights. In the upper row a red light indicates that the corresponding calibration lamp is lit. An orange light means that the lamp has recently been turned on and has not yet reached its working temperature. The lower row shows the position of the mirror which selects the light from the different lamps and sends it to the "45° mirror" which in turn reflects the light onto the CES main slit.

Wait until the flat field lamp is warm, then `Start single exp.` Plot the result with `GRAPHICS` and `FLAT-FIELD-graph`. If necessary change integration time and/or filters with `Special setting`. If the intensity peak does not fall close to the center of the frame you have to adjust the setting

by inserting the corrected value in the predisperser prism position window. If the peak is too far to the right try a lower value, if too far to the left a higher one. The full width of the graphics screen corresponds approximately to 40 predisperser encoder steps. Again press "ENTER" and wait until the slits and the prism have reached their new positions. The final peak position should be correct to within ± 2 units.

Note

The **Define single exp.** softkey always (except for *DarK* exposures) resets both slits to their correct working values as well as (if *ENabled*) resets the predisperser prism to its calculated position.

Once you have found the correct prism position you must disable its motor to ensure that you do not move the prism again. Do this by **Function disabling**. The following form (# 14) will appear:

```
* COUDE ECHELLE SPECTROMETER *          Disable/enable functions          * Form# 14

Lamp #1_1 2_1 3_1 4_1 5_1 6_1 7_1 8_1 (0=power always on, 1=automatic switching)

Motors: pred. entrance slit _1 (0=disable, 1=enable) scanner exit slit    _1
         scanner interm. slit_1          blue exit slit    _1
         calibr. lamp mirror _1          decker            _1
         filter                _1        red exit slit    _1
         predisperser          _0        short camera focus _1
         mod C, motor 3 (N/C)_1        mod C, motor 4 (N/C)_1

Predisperser initialisation__1 (0=at each positioning, 1=only at init)

Grating turn-table_____1 (0=off-line [panel] only, 1=on line also)
45 degree calibration mirror_1
Rear view mirror_____1
Large / Small field mirror__1
Detector shutter _____1
```

Press ENTER key to proceed (or softkey #1 to abort).

Insert a 0 for the predisperser. Press "ENTER" and check on the left screen that the predisperser really is disabled. The next **Define single exp.** will reset the slits but *not* move the prism. You may also disable the predisperser directly from the **Special setting** by entering DISabled in the second input window or by typing the command DIS,PRE. Keep the prism disabled until you change your working wavelength, at which time you have to enable it and thereafter repeat the

whole procedure. Also note that the displayed prism encoder value does not always correspond to a unique prism position. This value may be changed without a corresponding movement of the prism. Thus, you can not be sure to return to a previous prism position by giving the value you used previously. You may however use it as a first guess, but it has to be checked with the flat field lamp as described above.

Working with the prism in an erroneous position may result in a total loss of your signal. You may also experience gradient shifts in your flat fields or vignetting at either end of the spectral range. Even a moderate error in position results in a loss of efficiency. If the initial prism position given by the MULTI program for some reason is wrong by a considerable amount, you may find yourself working in a wrong diffraction order at a completely wrong central wavelength. If you can not recognize your spectral range this may be the reason. It is thus important that you really take the trouble to carefully check the prism position after every time it has been moved.

Flat field exposures

We are now ready to do flat fields. Appropriate exposure times and density filters depend on wavelength, resolution and the state of the flat field lamp and have normally to be found by trial and error. For 5893 Å and $R = 100.000$ an exposure time of 10 sec and filter No. 7 ($= 0.99$ D) gives an exposure level of ~ 2700 ADUs. Press Define single exp.:

EXPOSURE DEFINITION

Type	FF	
Exposure time	5 sec	Tape recording 0
Identifier	FF 5sec D=1.87	
Batch file	(Ignore)	Number of exposures 1
INSTRUMENT SETTING	1	
Calibration lamp#	6	Neutral density filter 2

and the rest unchanged.

“ENTER” and Start single exp. in the usual way.

Display by GRAPHICS and Flatfield-graph. This plots the flat field with the active dark subtracted. If you are satisfied repeat the procedure but do a series of ~ 5 exposures and save on tape. Do not forget the End of object. The last scanline will now be the active flat field exposure to be used later, for example to display stellar exposures when the CALIBRATED-graph key is used. An OBJECT is a raw-signal minus the active dark, a CALIBRATED-graph is a raw minus dark divided by the flat field minus dark.

It is good practice to take a series of flat fields at the beginning, the end and the middle of the night. One such series could contain 5 flats of a higher exposure level ($> \sim 1500$ units) and 5 with a level similar to the one you expect for your stellar exposures. If your stars are faint it is not necessary to completely match the level with your flats. An easy check of the flat field stability is to divide exposures taken at different times during the night. The result should of course be a straight horizontal line with very little noise.

For most purposes the internal quartz flat field lamp is sufficient to correct for the reticon pixel-to-pixel sensitivity variations. However, after all appropriate reductions have been made it is not uncommon to find a slight bending of the stellar continuum towards the blue end of the spectrum. This is probably a result of a slight difference in the way the slit is illuminated by the lamp and the star. You may improve this by taking flats on the inside of the dome or using (early-type) stars close to your target star in the sky, as continuum reference. Hot stars may also give a check of the earth's atmospheric lines.

Wavelength calibration

For wavelength calibration the Th-lamp (#2) is normally used. Exposure type is "CL" and typical exposure times are 15 sec to 2 min always without density filters. One higher and one lower exposure level is recommended to take advantage of lines of different intensity. Do wavelength calibrations at least with the same frequency as flat fields. Remember that strong Th-lines may leave a faint remnant signal for some time afterwards. If you are observing faint stars it may be better to do a series of Th exposures with a level just below saturation to further diminish the risk of these remnants. Averaging should give a sufficient S/N ratio also for the fainter Th lines. Clean with readouts before next exposure. If the very highest accuracy in wavelength calibration is required, do Th after each science exposure.

Check with a thorium line atlas (for example ref. [13]) that you really are working at the correct central wavelength. Using good Th wavelength tables very high accuracy may be reached; an RMS scatter of the line positions around the dispersion curve of 1 - 2 mÅ is typical. A second order polynomial based on ~ 15 lines is normally sufficient.

Long dark exposures

It is also necessary to check the dark current behaviour during long exposures. Some long darks should be made with the cover of the camera mounted to see the real internal dark of the reticon system. This dark is typically a few units (5-10) per hour. Repeat, but now leave all optics open in the same way as they are found during a normal stellar exposure. Close the lid of the focal reducer. If the test is done during daytime, check that the lights outside the CES room are turned off. There should be no significant difference between the darks obtained in these two ways, otherwise some parasitic light is present in the CES room.

Avoid flat fields or other exposures with strong light just before you intend to do long exposures of faint stars. There is a remnant effect in the reticon which is time dependent and appears as

a high dark current (see sections 2.5.3 and 3.2.2).

3.2.3 Science exposures

In a section below is described how to start up the CAT and how to find and center the object on the spectrograph slit. From figs. 5.1, 5.2, and table 2.1 you can estimate what exposure time you will need.

You must however take into account the difference in grating order efficiency between your central wavelength and those in the table. Furthermore, the choice of resolution and in particular the seeing at the time of observation, may strongly affect the required integration times. Check also the detector response curve as function of wavelength. In practice, it is far safer to do a short exposure on a bright star to get a first idea of the exposure time.

Stellar exposures are defined as RE (Regular). If displayed by **CALIBRATED-graph** the spectrum is automatically corrected for readout signal and flat field. Further reductions, as for example wavelength calibrations must be made with IHAP.

During the exposure you will have access to the following menu:

STATUS	Comments	EXTM,n	HELP
Pause exposure	GRAPHICS	IHAP	Abort exposure

The remaining exposure time is continuously displayed below this menu. The **Status** will show the requested and actual temperature of the reticon as well as the relative intensities of the video lines for the *previous* exposure (see beginning of section 3.2.2). **Comments** allows you to insert comments in the head of the current IHAP file. By **EXTM,n** you may change the exposure time by adding or subtracting a number of seconds. During exposures longer than approx. 5 min the internal readout clock of the reticon is switched off. This is done in order to avoid possible contributions to the dark noise from this clock. The status of the clock is indicated by two small red lamps on an Ortec module situated up to the left on the CES control rack. The same module also shows if the reticon shutter is open or closed. The clock is turned on automatically about 4 min prior to the end of the exposure to allow it to stabilize before the reticon is read. If you want to decrease your exposure time with **EXTM,n** you must take into account these 4 minutes.

The **Abort exposure** pressed twice aborts the exposure without saving it.

It is advisable to check now and then that all information in the IHAP file header is correct. Use IHAP command DLIST,#,L0, and check the UT, ST, coordinates etc.

To check the behaviour of possible periodic patterns in the reticon signal (see ref. [12]) a Fourier

transform (IHAP command FFTR) should be done on the spectrum after it has been flat field calibrated. The wavelength calibration tends to smear out possible Fourier peaks making the check less sensitive.

In general, it is highly recommended to continuously monitor the quality of the science exposures. During long integrations, the previously obtained exposures should be at least preliminary reduced and checked. Things like resolution, S/N ratio, continuum slope, presence of fringes and optical ghosts can be investigated during the night.

Other useful softkey menus

If the **--- ETC ---** key is pressed in the **GRAPHICS** menu the following submenu will appear:

Hardcopy - long	Hardcopy - short	Hardcopy w/o comm.	Help
Window & smoothing		Scanline pointers	MAIN MENU

The **Hardcopy - short** will copy the content of the graphics screen to the HP printer/plotter together with a table of the relevant optical parameters. **Hardcopy w/o comm.** will do the same but leave out the table. **Hardcopy - long** will turn the spectrum 90° and expand it to a larger size. The **Window & smoothing** will allow you to expand and smooth the spectrum by choosing start and end points in the X and Y directions as well as a Gaussian smoothing value. By **Scanline pointers** you may override the automatically defined pointers for the raw, dark and flat field exposures which are used by the GRAPH program for on-line reductions (see 3.2.2, Flat field exposures). The IHAP file number and the scanline number within the file have to be entered. These exposures will then serve as the 'active' ones until a new raw, dark or flat field exposure is made at which time the pointers will automatically be updated.

From several other softkeys found in different menus additional tasks may be performed:

- A sequence of exposures containing different exposure types may be defined and executed.
- The reticon and the CAMAC modules may be reinitialized.
- In case of problems, the last exposure may be read once again directly from the reticon controller buffer.
- A more extended logging system, independent of the automatic dump on the Epson printer, is available.

3.2.4 Closing down

In the control room:

- If you are going to use the CES at the same central wavelength the next night you may leave the MULTI program running. Only check that no calibration lamps are on. This will make the start the next day easier since the predisperser will remain disabled and close to the correct position. It has to be checked again however. Furthermore, all calibrations have to be repeated in the afternoon the next day. If you are going to change wavelength you may stop the MULTI by pressing **Terminate** and then **FINISH** twice.
- Check that the exposure meter shutter is closed.
- Dismount the magnetic tape. Press “RESET” and “REWIND”, wait until tape is at loadpoint, then press “REWIND” again. The tape will snap loose from the lower reel. Fill in the small label and place it together with the tape. The tape should be brought to the “DATA TAPES” mailbox outside the dining room. Here it will be picked up by the computer centre operators and copied into the La Silla data bank. At the end of the observing run all your observations will be collected on separate tapes and given to you. Standard format is IHAP 1600 bpi. If you have other wishes for the format contact the operators.

In the slit room:

- Close shutter in front of focal reducer.

In the spectrograph room:

- Place cover on collimator mirror.
- Mount the grating cover *very carefully*. Four corner pins on the table fit into corresponding holes on the cover. Gently tighten the corner screws. Check that the Hartmann screens are closed.
- Place cover on Maksutov camera.

Fill in the Telescope Operations Report. The white original should be placed in a binder situated in the control room. The pink and blue copies should be brought in the morning to the red box at the hotel entrance. Problems encountered during the night should be described in the Report as well as all types of suggestions and comments on instrument behavior.

3.3 The CCD mode of the Long and Short Camera

The operation of the CCD is very similar to that of the reticon, the largest difference of course being the fact that CCD images are two-dimensional. The spectrum is aligned with the direction of the CCD columns, one column being 1024 pixels in length. CCD exposures can only be handled with IHAP. The GRAPH program is not available. Every exposure is one file. A RAMTEK system is available for two-dimensional image display. The left-most HP-terminal is used by IHAP as graphic display, an HP pen-plotter serves as hardcopy device.

3.3.1 Starting up

Very similar to the reticon procedure. The dewar of the CCD normally does not need any attention. If the operating temperature of the CCD is wrong a warning will be given by the MULTI program. Turn on the power of the RAMTEK TV monitor, adjust contrast and brightness. Leave in on for the rest of the observing run.

3.3.2 Calibration exposures

It may be advantageous to use a rather long slit (15"–20"). The width of the flat field should be substantially larger than the stellar image caused by seeing and guiding errors. When doing long exposures on faint objects a check of the sky on either side of the object may be of value.

Since the CCD pixel size in the dispersion direction is similar to the reticon pixel size, the long camera with the CCD can be used at similar working resolutions. It is, however, also possible to "bin" the CCD in both directions. One should especially consider binning in the direction perpendicular to the dispersion to increase the signal/readout noise ratio. Binning in the other direction should of course be matched by a corresponding decrease in defined resolution.

The area covered by the spectrum on the CCD is only a smaller part of the full CCD frame. This area, with the addition of a some adjacent columns on each side of the spectrum for background monitoring, is the only one to be written on the tape. The pixel coordinates defining this part of the CCD as well as the binning factor, are entered from a softkey found under the CCD menu. If binning is selected, all exposures should be done with the same binning factor.

If the full spectrum is displayed on the TV monitor, the resolution is insufficient to show all individual pixels. This should be kept in mind, for example, when checking high exposure levels for saturated pixels. Another way of checking for saturation is to use the IHAP command "MAXMIN".

The spectrum should be aligned with the CCD columns to within a fraction of a pixel width. The alignment is made during the set-up of the CCD but it should be checked by the observer.

Readout bias level

A short dark exposure will show the level of the CCD bias. The bias value is normally between 180–200 ADUs (one ADU $\approx 7.4\text{ e}^-$). The bias level (expressed as a real number, not the image) should be subtracted from all subsequent exposures.

To display a CCD exposure enter IHAP and use the softkey `BATCH,KDISPC,,#` followed by the file number. KDISPC is a batch program that will calculate cut levels and display the file on the TV monitor. Other useful IHAP commands can be found in the three available menus.

Predisperser position check

This is done in the same way as with the reticon. Use the IHAP commands TRACE + TRAN or XADD + TRAN to get a one-dimensional display of the intensity peak on the HP graphics terminal.

Flat field exposures

Procedure is similar as with the reticon. The saturation level is around 16380 ADUs. (See section 2.5.2). Approaching this level the CCD may show non-linearity effects. At longer wavelengths ($\gtrsim 6500\text{ \AA}$) where strong interference fringes develop, it is safer to complement the internal lamp flat fields with dome flats. If the fringing is severe, try to use early-type stars close to the target star in the sky as flat fields. Make sure you illuminate the same pixels on the CCD in both cases. Even better is to turn off the autoguiding and slightly trail the flat field star along the slit. Under all circumstances should you check that you do not divide your science exposure with flat field pixels which have not been sufficiently exposed. The fringes have so far shown an unpredictable behaviour, sometimes they are large but stable in position and strength. At other occasions they have changed with time and the way in which the flat fields have been done.

Wavelength calibration

See reticon calibration. Like the reticon, the CCD also suffers from remnant charges but to a much lesser degree. After exposure to strong light, it should be sufficient to wait a few minutes and then make two or three readouts to reduce the remnants below the detection level. Saturation may also temporarily increase the readout noise.

Long dark exposures

The dark current of CCD #9 is very low, less than $2.5\text{ e}^-/\text{pix}/\text{hr}$. It can in most cases be ignored since the contribution from the readout noise is substantially higher ($33\text{ e}^-/\text{pix}$). It is

however still useful to do some long darks with the spectrograph open to ensure that no parasitic light is present in the CES room.

3.3.3 Science exposures

Since the physical length of the CCD (15.6 mm) is about half that of the reticon (28 mm) the useful spectral range for the long camera is smaller in proportion. Table 1 gives the spectral range as a function of wavelength and grating order for the three different combinations of camera and detector.

Exposure times can be estimated from the information given in chapter 5. If an integration time longer than approximately 2 hours is foreseen, it may be advantageous to split it in two exposures. Blemishes due to radiation events are then much easier to identify and remove. Binning reduces the contrast of the radiation blemishes since these are smeared out over a larger area of the CCD.

It is essential to check that all calibration exposures for the central wavelength under investigation have been made before an attempt is made to change wavelength range. Even though the CES is a very stable instrument, care should be taken in doing all calibration and science exposures under identical conditions.

Chapter 4

Trouble-shooting

4.1 In case of problems

If you encounter problems with the CES or the CAT which require intervention from the Observatory staff, please contact the Operations Group, paging no. 93 + 54 (day time) or 93 + 34 (night time). You may also get help from your introducing astronomer, the resident astronomer (paging no. 93 + 23) or the astronomer in charge of the CES. Do not hesitate to call any of these people, they are there to help you. It is important that you write down a description of the problems in the Telescope Operations Report. If a solution can not be found during the night, repairs based on this description will be attempted during the following day.

4.2 Currently known problems

- Drift of the predisperser position encoder. See section 3.2.2.
- At several central wavelengths a ghost image may appear as a spot of light approximately 1 - 1.5 Å in length superimposed on the spectrum. This ghost probably originates as a reflection between the grating and some part of the Maksutov camera. It cannot be removed at the present. If it disturbs your spectral lines try to shift the central wavelength. The ghost is almost stationary, it will move only slightly when the wavelength is changed. Proper flat fielding will only partly remove it.
- If a malfunction occurs in one of the motors driving the slits, decker, mirrors etc., it may help to reinitialize it. In the **OBSERVATION** menu press **ENGINEERING** and then **Initialize motors**. Form #11 will appear:

Coude echelle Spectrograph

* Initialize motor * Form 11 *

Initialize motor 5

0= All motors belonging to instrument in use (+CAMAC Z)
1= pred. entrance slit
2= scanner exit slit
3= scanner interm. slit
4= blue exit slit
5= calibr. lamp mirror
6= decker
7= filter
8= red exit slit
9= predisperser
10= short camera focus
11= mod C, motor 3 (N/C)
12= mod C, motor 4 (N/C)

Press ENTER key to proceed (or softkey#1 to abort).

Type the code for the motor in question in the window, press "ENTER".

- As reported by several observers, a shift in wavelength of up to two pixels may occur during the night. This serious problem is currently under investigation. If you want the highest accuracy in radial velocity you must at present take a Th after each exposure. In order to avoid as far as possible remnants use short exposure times. As a check of the zeropoint only a few lines are necessary.
- The dome flat field lamps show sodium in emission.

Chapter 5

Instrument performance

5.1 Total efficiency

Table 2 presents the total CES + CAT efficiency rates at a number of wavelengths as derived from measurements of a series of flux standard stars. The values express the percentage of photons detected by the CCD as compared to the number entering the CAT. A large slitwidth was used to avoid effects of varying seeing. In calculating the number of arriving photons the following formula was used:

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

S is the surface area of the CAT mirror in m^2 ($=1.47$), N_{λ} the number of photons at wavelength λ incident on the CAT per second and Ångström. La Silla mean extinctions have been used for A_{λ} . X is the airmass. The monochromatic magnitude per frequency unit, m_{ν} , is found from the tabulated values of the flux standards. A conversion factor of $7.4\text{e}^-/\text{ADU}$ (CCD # 9) was used to derive the number of events registered by the CCD.

When interpolating in table 5.1, the grating order efficiency and the RQE of the CCD have to be considered. Similar measurements remain to be done for the reticon and the scanner modes.

Table 5.1: Efficiency of the CES + CAT

Wavelength	3500Å	4035Å	4435Å	5400Å	6450Å	8092Å
Short Camera + CCD	0.26%	5.5%	9.1%	12.5%	12.5%	6.2%
Long Camera + CCD	—	—	—	10.1%	9.2%	3.1%

5.2 Expected S/N ratios

Figure 5.1 has been derived with the help of the efficiency values at 5400 Å. It shows the predicted S/N ratios as a function of V-magnitude and exposure time for the short camera and CCD #9. The relations are valid for λ 5500 Å and for the broad slit of 3.6".

Figure 5.1 is based on the formula

$$S/N = \frac{3600N_0T \times 10^{-0.4(m_\lambda - m_0)}}{(3600N_0T \times 10^{-0.4(m_\lambda - m_0)} + (Wb^{-1}N_r)^2 + W^2TD)^{0.5}}$$

where N_0 is the efficiency in $e^-/s/\lambda\text{bin}$ for a star of magnitude m_0 . Magnitudes are here defined in the normal way per unit wavelength. W is the width of the spectrum in pixels, N_r is the readout noise in e^-/pix and D is the dark current in $e^-/\text{pix}/\text{hr}$. T is the exposure time in hours and b the binning factor perpendicular to the dispersion direction. For CCD # 9 N_r is 33 e^-/pix and $D=2.5$ $e^-/\text{pix}/\text{hr}$. For the short camera a reasonable value of W is 5 pixels. Since the readout noise is the dominant source of noise at fainter magnitudes, binning should be considered. Fig. 5.1 shows two cases, no binning ($b=1$) and binning over two pixels ($b=2$).

The expected S/N ratios for the long camera and CCD # 9 are shown in Fig. 5.2. The value of W was 9 pixels in this case.

5.3 Spectral resolution

Table 5.2 summarizes the spectral resolutions which can be achieved with the long and short cameras.

The double pass scanner can be used with resolving powers up to approximately 210.000; the single pass mode can reach ~ 150.000 . When the scan is defined the resolution may be entered directly or calculated from the slit width or the resolving power in the same way as for the CCD or the reticon. The length of the spectrum can be defined or calculated from the number of channels. The channel width in turn is set to half a resolution element according to the Nyquist criterium.

5.4 3.6 m fiber link

During the March 1988 tests (ref. [9]) of the fiber link between the 3.6 m and the CES equipped with the short camera, a resolving power of 70.000 at 5900 Å was measured. Since the CES in this configuration is fed from an image slicer with a fixed output window the resolving power is also fixed at a given working wavelength. At 4000 Å the resolving power is expected to be of the order of 60.000.

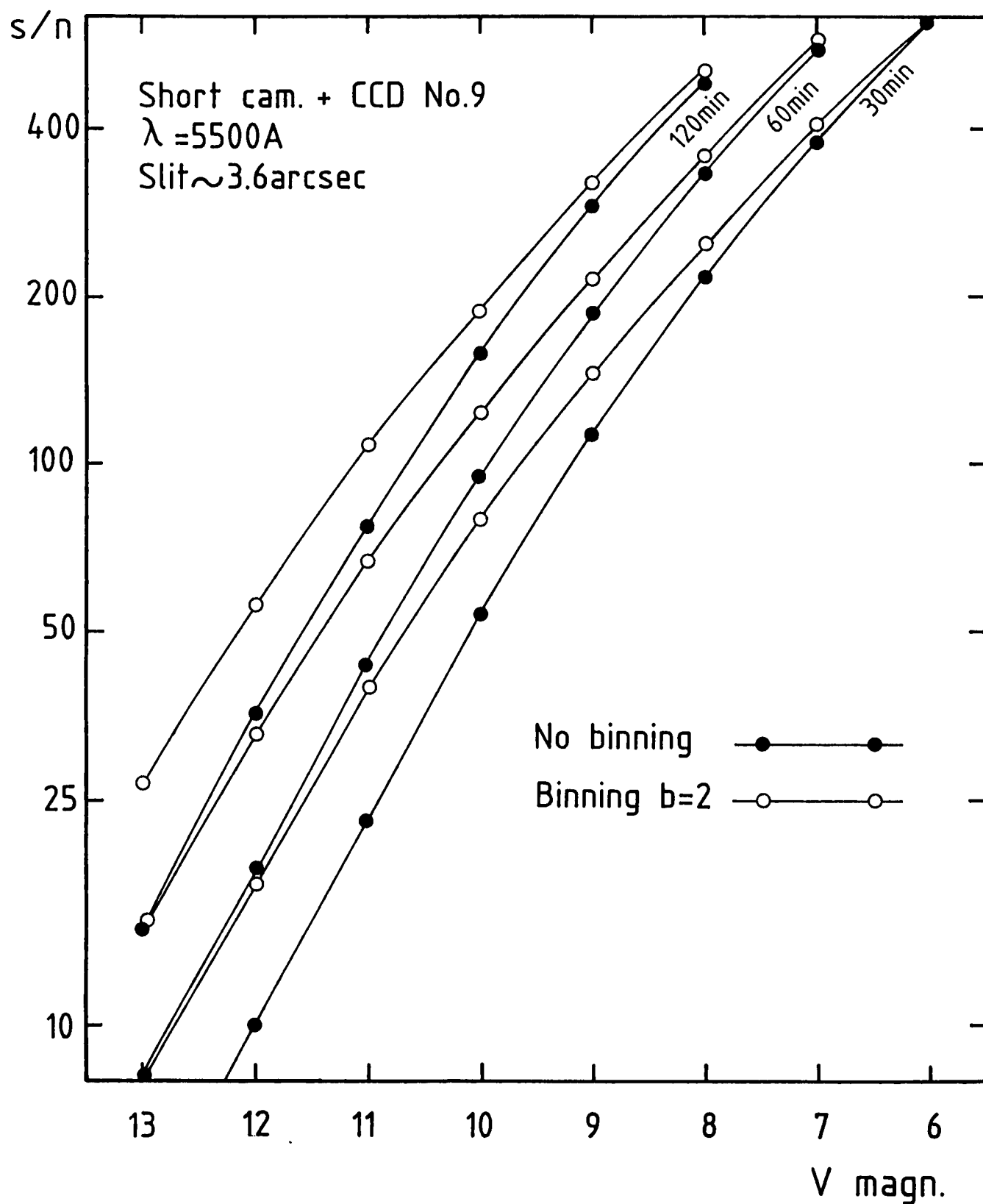


Figure 5.1: Expected S/N ratios for the Short Camera and CCD #9.

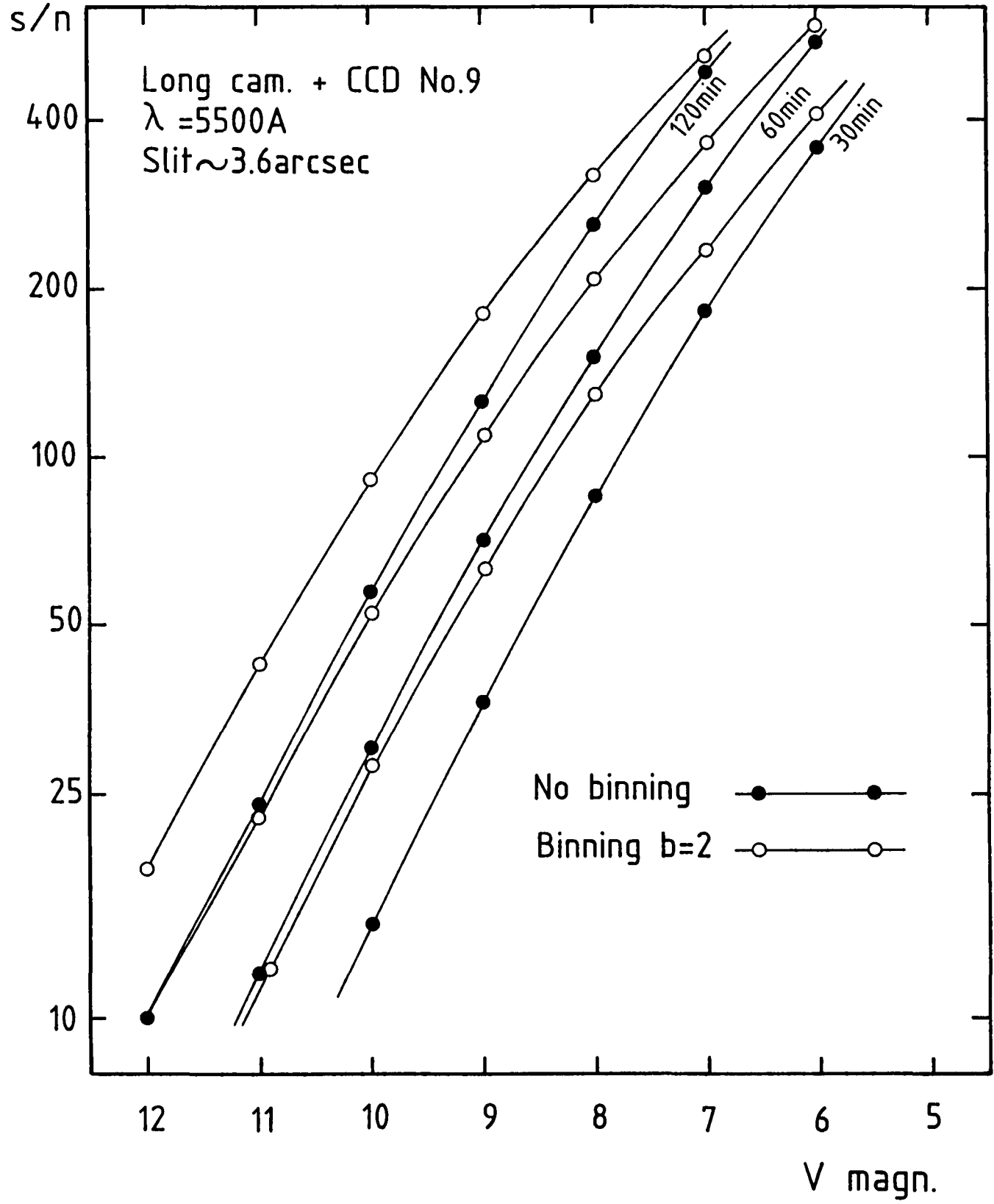


Figure 5.2: Expected S/N ratios for the Long Camera and CCD #9.

The total efficiency was measured to be such that 1 photon/Å/sec was detected at 5900 Å from a star of magnitude $m_{5900\text{Å}} = 16.5$. The corresponding value at 4000 Å is expected to be $m_{4000\text{Å}} = 15.6$.

Table 5.2: Spectral Resolution of the CES

LONG CAMERA + CCD OR RETICON						
Wavelength (Å)	Order	Disp (Å/mm)	Res. power 60.000	Res. power 80.000	Res. power 100.000	
			Spect. res. (mÅ)	Spect. res. (mÅ)	Spect. res. (mÅ)	
4000	57	1.12	66.7	50.0	40.0	
5500	41	1.63	91.7	68.7	55.0	
7000	32	2.13	116.7	87.5	70.0	
			Pixels/ Resol. elem.	Pixels/ Resol. elem.	Pixels/ Resol. elem.	
4000	57	1.12	4.0	3.0	2.4	
5500	41	1.63	3.8	2.8	2.3	
7000	32	2.13	3.7	2.7	2.2	
			Entr.slit width " μm	Entr.slit width " μm	Entr.slit width " μm	
4000	57	1.12	2.2 498	1.6 373	1.3 298	
5500	41	1.63	2.1 470	1.5 352	1.2 282	
7000	32	2.13	2.0 458	1.5 343	1.2 275	
SHORT CAMERA + CCD						
Wavelength (Å)	Order	Disp (Å/mm)	Res. power 30.000	Res. power 45.000	Res. power 60.000	
			Spect. res. (mÅ)	Spect. res. (mÅ)	Spect. res. (mÅ)	
4000	57	2.05	133.3	88.9	66.7	
5500	41	2.97	183.3	122.2	91.7	
7000	32	3.89	233.3	155.6	116.7	
			Pixels/ Resol. elem.	Pixels/ Resol. elem.	Pixels/ Resol. elem.	
4000	57	2.05	4.3	2.9	2.2	
5500	41	2.97	4.1	2.7	2.1	
7000	32	3.89	4.0	2.6	2.0	
			Entr.slit width " μm	Entr.slit width " μm	Entr.slit width " μm	
4000	57	2.05	4.3 992	2.9 662	2.2 496	
5500	41	2.97	4.1 942	2.7 628	2.1 471	
7000	32	3.89	4.0 915	2.6 610	2.0 458	

Chapter 6

CAT operating procedure

Details on the CAT control system can be found in ref [10].

6.1 Starting up

When the dome is being closed or opened, the mirror covers must be CLOSED.

In the dome:

Check that the CAT is free to move without danger of colliding with ladders, chairs, the flat field lamp assembly etc.

Check that the dome rotation, hatch 1 and hatch 2 switches are in a vertical (inactive) position.

Set the Local/Remote switch to Remote.

In the control room:

Check that 'COMP' switch is on (power to the CAT computer).

Switch 'SERVO' power on.

Push 'ON-LINE'.

The status of the CAT is displayed on the upper HP screen:

```

C o u d e - A u x i l i a r y - T e l e s c o p e
- - - - -
Control          Instr.          Detector
-----
      Shhmmss.s          Degr.          km/h          Cels.
Hour angle   24611.4   Zen.-dist.:40.9   Wind:----   Outside temp.:-----
Sider.time: 165033          Airmass:1.323          CAT-Dome temp.:-----

Focus pos.: 2570   Mirror 2: BLUE
-----
Telescope status   Autoguider status   Cover status   Dome / Hatches
Roll   : OPEN LOOP   Autoguider OFF   Mirror 1: CLOSED   Mode:   Manual
Pitch  : OPEN LOOP           Mirror 2: CLOSED   Low.hatch:   UP
Mirror3: OFF LINE           Mirror 3: CLOSED   Upp.hatch:   UP
Initialized: YES                                Ringseal: UNDEFIN.

      HATCH WILL OBSCURE WITHIN 15 MINUTES

East  [------z-----] West   37.2Deg.Roll
      ~
North [------z-----] South -27.3Deg.Pitch
      ~
```

Check against the CERMÉ display that the TCS (Telescope Control System) sidereal time is correct.

Select the main TCS menu on the lower HP-display and hit the CONSTANT HANDL. key. Check that the date is correct.

From the main menu go into the DOME/HATCH CNTR. and from this press Upp.Hatch UP to open the upper hatch. Wait until the hatch has stopped moving. This can be checked on the upper main status screen-display as well as by the small yellow control light on the CAT control panel. This light is lit during movement and goes off when the hatch is completely open.

Push 'OPEN' button on telescope panel. This will open the covers of the telescope mirrors. Wait until lamp goes on. Also check that the covers have been correctly opened by looking at the status display; mirrors 1, 2 and 3 should show 'OPEN'. In order to protect the mirrors, the hatches should always be opened *before* the mirrors.

Select your secondary mirror, normally 'RED' or 'BLUE' according to the wavelength you are working at. The limit between blue and red is $\sim 5200 \text{ \AA}$.

Press 'INIT' and wait until the light of this button goes off and the 'SLEW' light goes on. This operation initializes the telescope coordinate system and leaves the telescope close to zenith.

Check on the status screen that all telescope functions have been properly initialized; Roll and Pitch: Tracking, Mirror 3: Operative, Initialized: Yes.

Switch on the power to the finder TV and the monitor (only when the sky is sufficiently dark). Turn the gain to near maximum; during the night set it according to the brightness of your stars. Normally the pointing of the CAT should be good enough to allow you to identify your field from the 'Large field' mirror setting of the CES without use of the finder telescope. At some telescope/dome positions the finder may be obscured by the dome.

Switch on power to the integrating slit-viewing video system and its TV monitor. The main (red) power switch is located to the left on the panel above the terminal. To the right is the black (HV) gain control turn button. At start, leave the gain turned down completely. Be careful when you do calibration exposures not to damage the TV camera with too much light. This is specially important when using the flat field lamp. To see the CES slit use the thorium lamp and the 'Small field' mirror position. Check that you have the slit in focus. The TV focus control is to be found on the right side of the monitor. Remember to focus on the vertical slit-jaws and not on the horizontal decker.

Switch on the autoguider with 'ON'. During operation the following push-buttons should be lit on the Cross Hair Generator control box: 'CROSS HAIR', 'SIGHT BOX', the four box dimensions, 'W on B', '312', 'AUTO' and 'DOT'.

To center the cross on the slit, turn on the thorium lamp (by defining a CL exposure or typing the command `LAMP,2,ON`) and select the 'Small field' view. Increase the gain of the TV camera slowly until you see the slit clearly. From the main softkey menu go into `AUTO-GUIDER` and from this to `CROSS-HANDLING`. Find the (0,0) location of the cross by pushing `Center cross`. Then `Position cross` will move the cross to the coordinates you specify in the form that will appear. By trial and error center the cross in the middle of the slit. Choose an almost square box with, for example, a height approximately the same as for the slit and a width a few times larger than the CES slit. The relative position of the slit and cross may change slightly during the night. Adjust if necessary.

The videosignals in the four quadrants formed by the cross and the box are used to drive the autoguider in such a way as to keep these signals equal. A binary display of these can be seen down at the floor of the right-most panel. When the telescope is under autoguider control it is in off-set mode. The integrating time of the autoguider is around 1 sec. When attempting to guide on faint objects it may pay off to change the lower detection level of the autoguider. The maximum and minimum offset steps can also be changed from the autoguider menu. The autoguider may work on any pointlike object not necessarily situated in the slit, but not on extended objects. The field rotation has to be kept in mind if the autoguider is used outside the slit.

6.2 Telescope pointing and guiding

Check first on the main status display that the dome is in automatic mode. If not, go into

DOME/HATCH CNTR. and press **Autom/Manual**.

The CAT TCS program employs a catalogue handling system. In the main menu press **CATALOGUE** and then **Coordinate entry**. Fill in the identifier, alpha, delta and the epoch. You must type the decimal points in alpha and delta. Press the 'ENTER' button on the terminal. If you want to see the content of the catalogue use **List catalogue** and give the location of the first object you wish to display followed by the number of objects. Press 'ENTER'. The whole catalogue will be written if you leave the input fields empty.

The telescope pointing is done from the **PRESETTING** menu which can be reached from the main menu or directly from **CATALOGUE**. If your object is already in the catalogue use the **Go to object** key. Give the identifier (or the object number in the catalogue) and press 'ENTER'. You can also point by **Go to coordinate** in which case you have to provide the coordinates.

Select the 'Large field' mirror. You should now see your object in the finder telescope monitor as well as in the CES slit view monitor. Move the object close to the center of this screen. Go into 'Small field' and center the star on the slit. Adjust the TV gain until you clearly see the wings of the stellar image on the slit decker. For faint objects you may have to use the integration mode.

Start the autoguiding: Press **AUTO-GUIDER** then **Autoguiding ON**. The telescope should go into OFFSET mode and start to move the star into the slit. The light of the corresponding alpha or delta control button goes on momentarily when the correction is performed. You are now ready to start your science exposure. During long exposures it may be necessary to change the position of the lower hatch. Remember to reset the dome to automatic mode.

6.3 Closing down

- Switch off power to the TV camera on the finder telescope. Monitor off.
- Turn down the gain of the CES slit view camera. Main switch and monitor off.
- Push 'CLOSE' and wait until the lamp is lit. It should take about one minute. The telescope will move to the zenith and the mirror covers will close. Check on status display.
- Close the hatches from the **DOME/HATCH CNTR** menu. Wait until they are fully closed. Again check the status display and the small control lights to the left on the CAT panel. Do not close hatches prior to telescope covers.
- Switch off 'ON-LINE', 'SERVO' and 'COMP'.
- Go to the CAT dome and switch the dome control to 'LOCAL'.

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