EUROPEAN SOUTHERN OBSERVATORY

OPERATING MANUAL

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PHOTOELECTRIC PHOTOMETERS

Photoelectric Photometers

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Chapter 1

Introduction

The following photometric systems are presently supported on La Silla.

- Johnson UBV (1m, 0.5m ESO)
- Cousins UBV$(RI)_c$ (3.6m, 1m, 0.5m ESO)
- Strömgren *uvby* (3.6m, 1.5m Danish, 1m, 0.5m ESO, 0.5m Danish)
- Hβ wide/Hβ narrow (3.6m, 1.5m Danish, 1m, 0.5m ESO, 0.5m Danish)

The general definition of the various photometric systems as well as the implementation at La Silla are discussed in Chapter 2. Chapter 3 describes the photometers, the data acquisition programs and transformations from instrumental to standard systems as well as measuring performance. All ESO photometers use photon counting electronics.

Output from the data acquisition programs is on magnetic tape. For observatory supported systems, the data can be reduced at the La Silla computing centre by means of the general purpose photometric reduction program SNOPY. This program is implemented in both the VAX and the HP computers.

Other photometric systems can be used by the visiting astronomer made up either from the ESO filter list, or by filters provided by himself. Details on the various photomultipliers are given in Chapter 4. Dead time determinations, information on photometric conditions at La Silla and extinction values, as well as filter transmission curves can be found in the appendices.

Chapter 2

Photometric Systems Supported at La Silla

2.1 The Johnson UBV System

For now historical reasons the original UBV system has been reconstructed in several slightly different ways. Landolt-Börnstein (p. 50, vol 2.b) gives two examples taken from Johnson (1955) and Haug (1980). Haug used the 50cm ESO telescope on La Silla. Total response functions are given on page 48 of the same volume.

	Filter	Alternative	Tube
Johnson			
U	Corning 9863	2mm UG2	RCA 1P21
B	Corning 5030 + 2mm GG13	1mm BG12 + 2mm GG13	
V	Corning 3384	2mm GG11	
Haug			
U	2mm UG1 + 2mm WG335		EMI 6256S
B	1mm BG12 + 4mm GG385	GG385=GG13	
V	2mm OG515		

The WG335 was added to get an instrumentally defined shortwave limit of the U band. Extensive work has been made at Vilnius (Ažusienis and Straižys, 1966, 1969) to reconstruct the UBV system but the technical realization is the same combination of filters and tubes as above.

At La Silla the Johnson UBV is implemented with an EMI 9789QB tube and the following filters (see Appendix A for ESO numbers and transmission curves):

U	2mm UG2
B	1mm BG12 + 2mm GG385
V	2mm GG495

The 9789QB replaces the S11 type 6256. These tubes have similar red response limits which define the red end of the V band.

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2.2 The Cousins UBV and V(RI)$_c$ System

The UBV part of this system is on the Johnson one while the RI defines a colour system in its own right. The original realization of the Cousins VRI system is summarized in Landolt-Börnstein, Vol. 2b page 83:

Symbol	Filter	Multiplier/Telescope	Lambda mean
V	2mm Omag 302	RCA "Quantacon"	5500:
		Ga As photocathode	
R	Interference	18″ reflector	6700
I	3mm RGN9		8100
V	3mm GG495+1mm BG 38	EMI 9659A	
		extended S20	
R	2mm OG570	20″ reflector	
I	Wraten 88A		
R	2mm OG570+2mm KG3		6500

Note that the red side of the V band now is filter-defined. Original response functions for the VRI can be found in Cousins (1976b) and Bingham and Cousins (1974). The UBV part included the use of an EMI 6256 S11 with a quartz end window and Fabry lens but also a 1mm glass plate in front of the photocathode to remove some of the UV light not wanted for the U band. The filters were the following:

U UG2 (1mm)
B BG12 (1mm) + GG13 (physically 4mm, but optically 3mm)
V Omag 302 (2mm)

During later years all bands in the UBV(RI)$_c$ system were measured with a Hamamatsu R943−02 Ga-As tube operated at 1700V and maintained at −15°C in a Peltier cooled *Products for Research* cold box. Red blocking filters were added to the U, B and V bands:

U UG1 (1mm) + solid $CuSO_4$ (5mm)
B BG12 (1mm) + GG385 (2mm) + BG18 (1mm)
V GG495 (2mm) + BG18 (1mm)
Rc OG570 (2mm) + KG3 (2mm)
Ic RG9 (3mm)

As can be seen, the Quantacon has not been used in establishing the blue part (UBV) of the system. However, Bessell successfully duplicated the Cousins system using a Quantacon for all bands. The filters were (very similar to Cousin's later set):

U	UG2 (1mm) + $CuSO_4$ (crystal or liquid)
B	BG12 (1mm) + GG385 (2mm) + BG18 (1mm)
V	GG495 (2mm) + BG18 (1mm)
Rc	OG570 (2mm) + KG3 (2mm) or maybe KG3 (3mm) depending on individual filter differences
Ic	RGN9 (3mm) Red cutoff defined by the Quantacon tube

Bessell also remarks that extended S20 photocathodes such as in the selected EMI 9658 R or 9659 B tubes, can be used very successfully for UBVRI photometry. The effective wavelengths of the V, R and I passbands obtained with the extended S20 differ only slightly from those obtained with the GaAs tube and the standard star colour indices transform precisely. The very red-sensitive RCA 31034 A is the 'natural' tube of the Cousins VRI system. Cousins uses this tube at $-10°C$ while most other observers use dry ice cooling at $-78°C$ which produces slightly lower dark counts and a bluer red cutoff.

At La Silla the implementation of the Cousins UBV(RI)$_c$ system follows the recipe of Bessell, the filter types are the same. See Appendix A. Normally, the Quantacon tube is used but the red-sensitive EMI tubes as well as the Hamamatsu tube also work well.

At CTIO, Graham (1982) also used an RCA 31034 in a pulse-counting mode with the filter-set described below to establish a UBVRI standard star sequence on the Cousins system. The aim was to provide a number of fainter standard stars for use with large telescopes or for direct imaging. The filters used were:

U:	Corning 9863 + solid $CuSO_4$ cryst
B:	2mm GG385 + 2mm BG12 + 2mm BG18
V:	2mm GG495 + 2mm BG18
R:	2mm OG570 + 2mm KG3
I:	1mm RG780 + 3mm RG715

Graham notes that the short wavelength boundary of the U-band is mainly defined by atmospheric absorption while the long wavelength boundary of the I-band is determined by the cutoff of the photomultiplier.

For work in UBVRI in the southern hemisphere the Cousins system is the most used. It is well established through the standard star sequences in the E- and F-regions as well as in the Magellanic Clouds. The latest compilation of these sequences can be found in Menzies et al. (1989). Several other lists by the South African observers can be used as secondary standards (see the references below). Another standard star list has been published by Graham (1982). Landolt (1983) has published a list of equatorial standards for the UBVRI system using basically the same equipment as Graham.

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2.3 The Strömgren *uvby* and the Hβ System

For an early introduction to the *uvby* system see Strömgren (1963). Also useful are, for example, Golay (1974) and Straižys (1977). Original response functions (including the response of the 1P21 tube) which are based on Kodaira (1975) and Olson (1974), can be found in Landolt-Börnstein p. 57, and without the tube response in Matsushima (1969).

The original realization of the Strömgren *uvby* and Hβ system is given in the table below taken from Crawford and Barnes (1970), and Crawford and Mander (1966). Strömgren and Perry (1965) used the same filter set for their first defining catalogue. The tube was the RCA 1P21.

Strömgren *uvby* and Hβ:

	Filter	Peak wavelength	Half-width
u	8 mm Schott UG 11+	3500	380
	1 mm Schott WG 3		
v	Interference	4110	190
b	Interference	4670	180
y	Interference	5470	230
Hβ	Interference		
	Kitt Peak No. 212	4859	30
	Kitt Peak No. 214	4890	145

Standard star measurements made with this system are presented in the three references cited below. Numerous other publications by, in particular, Crawford and collaborators can be used as sources for fainter secondary standards. Many of these references are listed below.

Newer lists of standard stars are given by Twarog (1984) and Perry et al. (1987). Measurements of E-region stars has been made by Cousins (1985, 1989) as well as Kilkenny and Menzies (1986).

As indicated above, the original Hβ system on which most later La Silla observations are based, is the one described by Crawford and Mander (1966). The Hβ index is a parameter basically free from effects of interstellar reddening and line blanketing. It is used in derivations of effective temperatures and absolute magnitudes. Standard star lists can be found for example in Crawford and Mander (1966) as well as in later papers by Grønbech and Olsen (1977) and Perry et al. (1987). The latter papers give a very useful collection of references for standard stars in both the *uvby* and the Hβ systems. For the E-region stars, Cousins (1989) may be consulted.

On La Silla the Strömgren *uvby* and Hβ system is realized in two ways: The single channel photometers on the ESO 0.5m and 1m telescopes, with a purely filter-defined system, and the two six-channel spectrophotometers on the Danish 1.5m and 50cm telescopes, using a combination of filters and spectral slots to define the passbands.

For the ESO 1m and 50cm photometers the filter characteristics are given below. The tube is the EMI 9789Q.

	Filter	Peak wavelength	Half-width
u	8 mm Schott UG 11+	3495	320
	1 mm Schott WG 3		
v	Interference	4190	190
b	Interference	4635	167
y	Interference	5420	213
Hβ	Interference		
	Hβ narrow	4867	28
	Hβ wide	4845	143

In 1985, the two older Strömgren *uvby* and the separate Hβ photometers for the 0.5m Danish telescope, were replaced by the current six-channel instruments. The first part of the very large observing programme by Grønbech and Olsen was performed with these older instruments. In particular, this was the case for their *uvby* standard star list (Grønbech, Olsen and Strömgren, 1976). It is therefore of interest to give some details of these photometers. The four-channel photometer used a filter-set acquired from Kitt Peak with transmission curves fairly close to those used in the original *uvby* system (Crawford and Barnes, 1970, see above). The edges of the passbands were defined by slots cutting the spectrum produced by the photometer grating at positions where the filters transmission was less than 8% of maximum. The photomultipliers were of type EMI 6256SA operated at ambient temperature.

The Hβ two-channel instrument employed a beam-splitter which sent 20% of the light to the wide-band channel. Central wavelength, peak transmission and half-width of the filters were 4868Å, 67%, 28Å and 4865Å, 79%, 156Å respectively (Grønbech and Olsen, 1977). EMI 6256SA tubes.

The two new-generation combined six-channel spectrophotometers for the two Danish telescopes are similar except for the field- and diaphragm viewing system. Florentin Nielsen (1983, 1985) gives design details. The *uvby* filters and corresponding slots are defined by:

	Exit slot limits (Å)	Filter peak (Å)	Half-width (Å)
u	3324 - 3686	3505	330
v	4006 - 4222	4110	170
b	4572 - 4801	4685	183
y	5346 - 5635.5	5488	235

Filter peak transmissions range from 76% in *u* to 90% in *y*. The two Hβ filters are centered on 4864Å and have half-widths of 137Å and 30Å respectively. The photomultipliers are all EMI 9789QA selected for low dark current.

In general, data from the six-channel photometers transform well into the systems of Crawford and Barnes (1970) of Grønbech and Olsen (1976), at least for stars with spectral types earlier than G5. Olsen (1984) extended the system for dwarf stars of spectral types G, K and partly M. However, increasingly severe transformation problems are encountered for the m_1 and, in particular, the c_1 index for late-type giants (and supergiants). (Lindgren, unpubl.). However, for a more recent discussion of supergiant measurements see Gray and Olsen (1991).

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Chapter 3

The Photometers

3.1 The 3.6m Standard Photometer

Introduction

The 3.6m standard photometer is a single channel photometer which is mounted at the Cassegrain focus. The layout of the photometer is illustrated in Figure 3.1. The diaphragm wheel is slightly inclined to the image plane and its outer face is polished in order for the star field to be seen by reflection through the normal 3.6m TV viewing system in the Cassegrain adapter. This has the added convenience that guiding can be carried out on field stars during the measurement. The normal *Products for Research* dry ice or Peltier (for Quantacon) cold boxes are used. These have special combined Fabry lenses and entrance windows which reduce light losses. The cold boxes are not interchangeable with other photometers. The instrument is fully operated from the control room.

Diaphragms

Table 3.1: *3.6 m Photometer: Diaphragm Sizes*

Position No.	5/0	4/11	3/10	2/9	1/8	7	6
Diameter mm	0.56	0.98	1.40	2.10	3.08	4.2	0.7
Diam arcsecs.	4	7	10	15	22	30	mirror

The diaphragms are double; one for the star to be measured and the other for the sky background (see Figure 3.2). Diaphragms 0 through 6 are separated by 40 arcsecs, and 7 through 11 by 30 arcsecs. This allows four combinations of star/sky positions. However, as the sky chopping is not yet implemented, only one diaphragm of each pair is used as in a normal single channel photometer.

Diaphragm 6 is the target diaphragm used for centering the object. It consists of a small circular reflecting area acting as a mirror, with a diameter of 0.7 mm surrounded by a

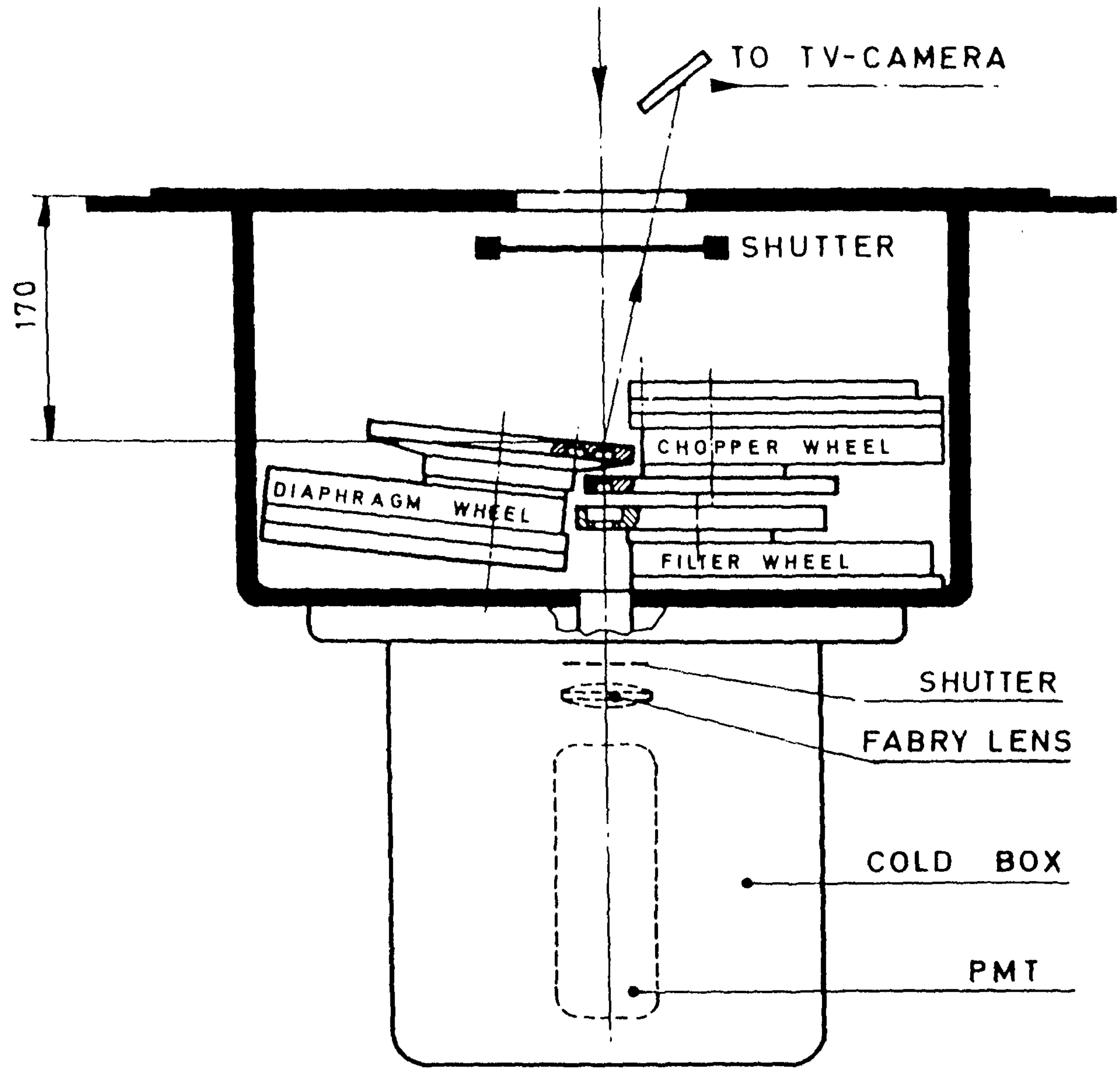

Figure 3.1: *The 3.6 m Standard Photometer*

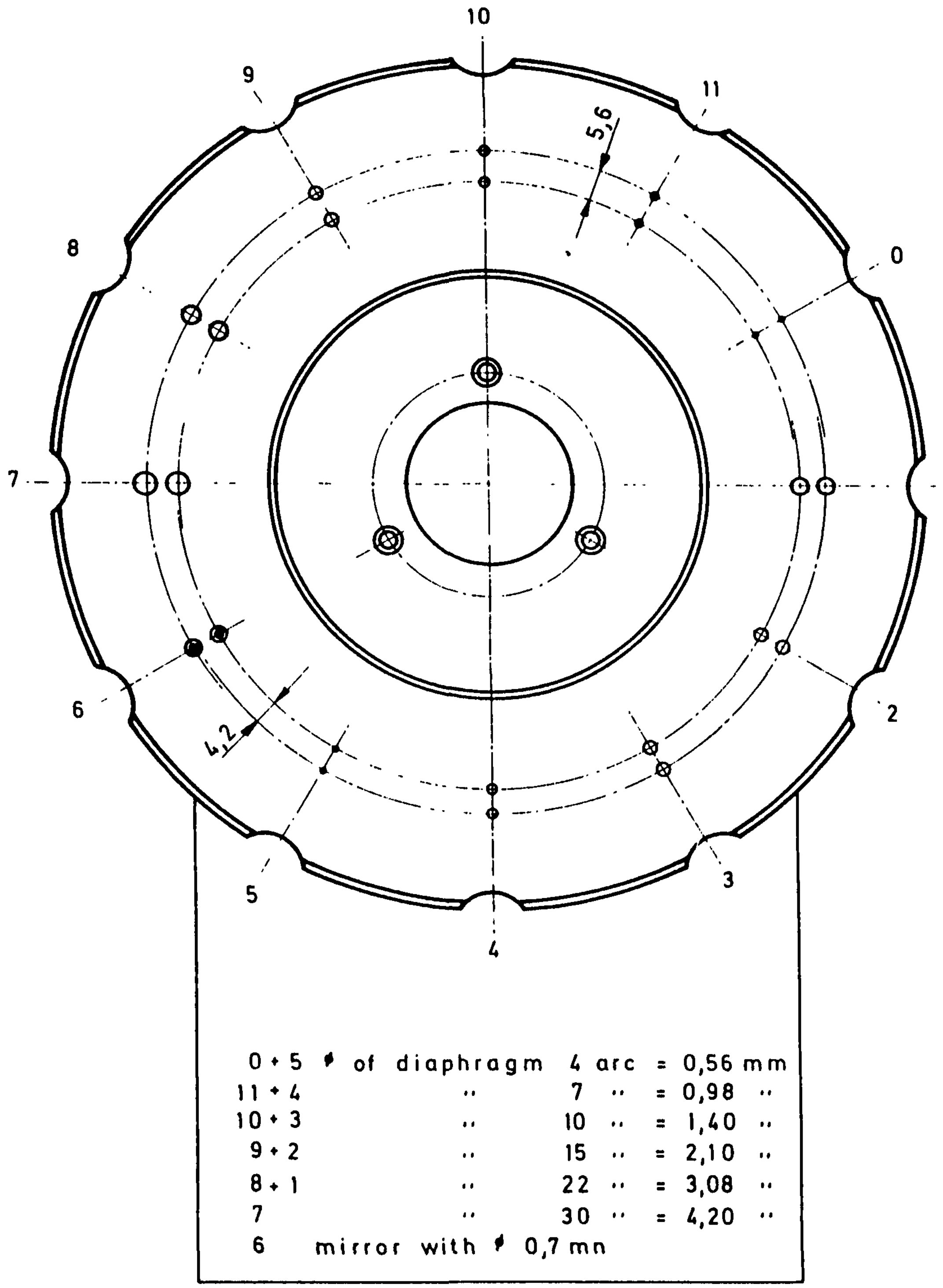

Figure 3.2: *Diaphragm Wheel for the 3.6 m Standard Photometer*

non-reflective ring. The center of all diaphragms coincide precisely when used in the beam. Thus, centering in No. 6 will ensure correct position when other diaphragms are moved into position.

Filters

The filter wheel contains up to eight filters numbered 0 to 7, which can be positioned automatically. The filters are 1 inch (2.5cm) in diameter and up to 10mm thick. A standard UBVRI set of filters is available. These filters are identical to those described by Bessell (1976) and are closely related to the Cousins system, (Cousins, 1973). For transmission curves see Appendix A. The standard positions of the filters are indicated in Table 3.2.

Table 3.2: *3.6 m Photometer: Standard Filter Wheel Positions*

Position	Filter	ESO #
1	free	
2	U	624
3	B	275
4	V	276
5	R	277
6	I	278
7	dark	
0	dark	

Photomultipliers

The list of photomultipliers available for the 3.6 m photometer is given in Chapter 4. The system uses standard pulse counting techniques.

Photometer Modes

a) *Normal Photometry.* In this mode, the 3.6 m photometer control program is very similar to that of the 1 m telescope, described in Section 3.3.

b) *Fast Photometry.* Fast photometry with sampling rates of up to 10 KHz is available. The control of the photometer program is done from two different consoles. One controls the filter wheel, the diaphragm wheel, and the shutter. *As the shutter is not controlled automatically from the acquisition system, the observer should close it between integrations.* A second console is used to start/stop an integration and to manipulate the magnetic tape. A strip chart recorder (useful to see "on-line" count variations) and a digital counter are also available. The output is on magnetic tape and, due to the quantity of data collected, the magnetic tape unit should be set to 6250 bpi. Note that with an integration time of 0.1 msec a tape is filled every 1.8 hours. The present timing stability of the fast photometry system is about 2 parts in 10^{10}.

Magnitude Limits

Typical count rates in UBVRI for a selection of stars are given in Table 3.3 for the UBVRI system using a Quantacon tube and a 15″ diaphragm. It is clear that stars brighter than V = 10^m should not be observed.

Table 3.3: *3.6 m Photometer: Typical Count Rates*

	V	B-V	U-B	V-R	V-I	U	B	V	R	I
	magnitudes					counts s^{-1}				
E9-g	12.70	0.89	0.68	0.51	0.93	3710	10980	17280	15000	13750
E9-k	13.96	0.54	−0.07	0.31	0.63	3500	5940	6870	5030	4400
E9-n	14.71	0.56	−0.07	0.34	0.68	2420	3840	4240	3125	2970
E9-s	15.57	0.52	−0.09	0.34	0.71	1900	2750	2900	2170	2220
sky			typical			1450	1900	1850	1350	1000

3.2 The Six-channel Photometer at 1.5m Danish telescope

3.2.1 Introduction

The new six-channel photometer for the 1.5m Danish telescope is a rebuilt version of the old four-channel *uvby* photometer. This new version includes the Hβ section and filters have been added to make it very similar to the Strömgren photometer at the Danish 0.5m telescope. Thus, for further details on the design see Section 3.5.

The main differences as compared with the 0.5m photometer are the following:

- A TV system is used to display the field view and the image of the diaphragm on a monitor in the control room. No eyepieces are mounted on the photometer itself.

- An optional depolarizer (90% transmission) may be inserted in front of the diaphragm wheel.

- The auto-centering facility is not implemented.

- The telescope control system is not integrated into the MONI program. It is thus not possible to operate the system in automatic mode.

3.2.2 Entrance Diaphragms

Six diaphragms are available as shown in Table 3.4.

Table 3.4: *1.5m Danish Six-channel Photometer: Diaphragm Sizes*

Position	Diameter	
	arcsec	mm
0	16	1.0
1	32	2.0
2	4	0.25
3	7	0.45
4	10	0.6
5	110	7.0

3.2.3 Viewfinder

The photometer is mounted on the instrument adapter. The adapter houses a field viewer with a circular field, 8 arcmin in diameter and a Quantex integrating TV system showing the central 3.5 x 3.5 $arcmin^2$. The TV system is also used with a periscope to center the star in the photometer diaphragm.

3.2.4 Photomultipliers

Six photomultipliers, type EMI 9789QA are used, operated at ambient temperature. They are fed by a common voltage supply (HV = 1150 Volts), but individual voltage drop resistors ensure that each photomultiplier receives the optimal voltage.

3.2.5 Brightness Limits

Stars brighter than $V = 6^{m}.5$ should not be observed without using neutral density filters. If the density filters are inserted the limit is $V = 4^{m}.0$.

3.2.6 Count Rates

Typical count rates for the *uvby*-section are given in Table 3.5. The 50% transmission *v* and *b* density filters have been used in deriving these values.

Table 3.5: *1.5m Danish Six-channel Photometer: Typical Count Rates for the uvby-section using the 50% v and b Density Filters*

Star	Sp	V mag	u	v (counts s^{-1})	b	y
HR 5998	B7III	6.33	406K	474K	300K	173K
HR 1006	G4V	5.54	273K	457K	457K	377K
HD 5913	dF6	11.26	1530	2760	2460	1880
HD 10720B	gK2	11.70	220	690	1210	1280

Count rate examples for Hβ measurements are given in Table 3.6.

Table 3.6: *1.5m Danish Six-channel Photometer: Typical Hβ Count Rates*

Star	Sp	V mag	HβN (counts s^{-1})	HβW
SA 106-653	G2V	9.66	2840	2240
SA 103-302	F3	9.86	2290	1810
SA 105-456	F3	10.26	1660	1380
SA 98-185	A2	10.55	1120	1080

3.2.7 Data Acquisition System and Observing Modes

The photometric data acquisition system is almost identical to that of the 0.5m telescope. However, only that part of the MONI program which controls the photometer is available. At the moment, the telescope has to be operated from the old TCS program. This means that it not possible to do observations in automatic mode neither does the autocentering facility exist. Every star to be observed has to be found and centered in the diaphragm manually and only the manual functions of the MONI program can be used. With the help of the integrating TV system, stars at least down to V = 15.5 can be seen and centered in the diaphragm.

3.3 The Single-channel Photometer on the 1m ESO telescope

3.3.1 Introduction

This photometer is mounted at the Cassegrain focus of the 1 m telescope. It is a conventional instrument consisting of the following components, given in the order in which they are encountered along the optical axis:

1. Offset guider/finder
2. Diaphragm wheel
3. Eyepiece to center the star in the diaphragm
4. Filter wheel
5. Photomultiplier mounted in a dry ice cold box, or Peltier cooler, depending on the type of photomultiplier used. The EMI 9789Q tubes do not require cooling.

The Offset Guider/Finder

It is equipped with a wide field eyepiece with a field of view of 7 arcmin. This eyepiece may be displace in the x and y directions by up to 13 arcmin to serve as a manual offset guider. The field is reversed and with the photometer mounted on the telescope with the viewfinder on the west side, north is right and east is down. An image intensifier can be attached to the eyepiece which allows stars down to V = 17 mag to be centered in the diaphragm on moonless nights.

The Diaphragms

The following diaphragm diameters are available:

Table 3.7: *1 m Optical Photometer: Diaphragm Sizes*

Position No.	1	2	3	4	5	6	7	8	9	0
ø (mm)	0.34	0.405	0.552	0.803	1.150	1.692	2.316	3.210	4.506	6.405
ø (arcsec)	4.10	5.47	7.47	10.85	15.54	22.87	31.21	43.37	60.80	86.55

Filter Wheels

Two filter wheels with 12 positions each are available. The wheels take filters up to 25.4 mm in diameter and up to 10 mm thick. The filters may be chosen from the ESO list or the observer may provide her/his own. In all cases, the visitor should inform ESO Staff through the request for observing time which filters she/he intends to use. This is to ensure that no conflicts with other telescopes occur and that the filters are available. When carrying out Strömgren or Johnson UBV photometry, the following filter sequence is normally used (and is default in data acquisition and reduction programs):

Table 3.8: *1m Optical Photometer: Standard Filter Wheel Positions for Blue-sensitive Photomultipliers*

Position	Filter No.	Position	Filter No.
0	HβN 326	6	Dark
1	HβW 327	7	Dark
2	*u* 322	8	Dark
3	*v* 323	9	U 113
4	*b* 324	10	V 111
5	*y* 325	11	B 112

For UBVRI photometry the standard positions and filters shown in Table 3.9 are used.

Consult the Operating Manual if a different choice of positions is made, and on-line magnitudes are required.

Table 3.9: *1 m Optical Photometer: Standard Filter Wheel Positions for Red-sensitive Photomultipliers*

Position	Filter No.	Position	Filter No.
0	B 284	6	Dark
1	U 283	7	Dark
2	Dark	8	Dark
3	Dark	9	I 287
4	Dark	10	R 286
5	Dark	11	V 285

3.3.2 Telescope and Photometer Control

Both the telescope and the photometer are controlled from two separate terminals in the dome. The telescope control system (TCS) and data acquisition system (PHOTO) are implemented on HP computers. The TCS handles telescope pointing, telescope drive and coordinate files. The PHOTO controls the photometer setting and handles data and output devices. It is linked to the TCS program. The TCS can handle a large number of coordinate catalogues each containing up to 500 objects. Coordinates can be typed into the computer, or read in from magnetic tape cassette, which can be prepared either at La Silla or elsewhere. The system will accept coordinates of any epoch. The photometer can be operated in a manual or an automatic mode. In the manual mode, the photometer is operated conventionally with every command for filter wheel rotation and to start or stop integrations being initiated by the observer. In the automatic mode, the observer initiates a predefined observing sequence. The observer can define a sequence of filter settings for object or sky measurements. The observer can also specify integration limits, (i.e. a minimum and maximum number of integrations), each of some integer number of seconds, or a mean deviation criterion (e.g. 0.5% accuracy). After initiation the sequence is performed under full computer control. If, for some filter setting, the mean deviation criterion is satisfied before the maximum number of integrations is reaches, the photometer moves to the next filter. Several override functions are provided by the PHOTO program. For further details consult the Operating Manual.

3.3.3 Magnitudes Limits and On-line Magnitudes

Objects should not be brighter than V = $7^{m}.0$ for UBV, V = 9^{m} for VRI, and V = $5^{m}.0$ for *uvby* photometry. *This is to avoid damage to the multiplier.* As mentioned above, stars down to V = 17th mag can be seen and centered in the diaphragm under good seeing conditions. For faint objects an accuracy of $0^{m}.05$ at 16^{m} and $0^{m}.1$ at 17^{m} can be obtained. Typical count rates with diaphragm #5 (15 arcsec) are given in Tables 3.10 and 3.11.

Table 3.10: *1 m Optical Photometer: Typical Count Rates for UBV System*

Star type	V mag	U	B (counts s^{-1})	V
B3	7.9	62 K	300 K	78 K
A1	9.7	6 K	53 K	16 K
sky	typical	100	300	250

On-line magnitudes may be calculated using average values for extinction and transformation coefficients. Measurement of at least one standard star is required to fix the system zero-points.

Table 3.11: *1 m Optical Photometer: Typical Count Rates for UBVRI System*

	V	B-V	U-B	V-R	V-I	U	B	V	R	I
	magnitudes					(counts s^{-1})				
E8-47-V	10.62	0.51	0.08	0.30	0.58	1525	3280	4160	3110	2500
E8-A	12.10	0.60	0.10	0.35	0.69	365	805	1100	888	820
E8-H	13.31	0.59	0.00	0.35	0.70	145	287	393	325	367
E8-p	14.72	0.76	0.41	0.43	0.80	44	93	141	139	213
sky	typical					25	30	45	55	140

3.4 The Single-channel Photometer at the 0.5 m ESO telescope

3.4.1 Hardware and Control Software

This photometer is mounted at the Cassegrain focus of the 0.5 m ESO telescope. It is a conventional single-channel photometer consisting of the following components, given in the order they are encountered along the optical path, (Fig. 3.3):

1. Wide field viewfinder
2. Diaphragm wheel
3. Eyepiece to center the star in the diaphragm
4. Filter wheel
5. Photomultiplier, at ambient temperature or with thermo-electric or dry-ice cooling.

An image intensifier eyepiece is also available. The system uses standard pulse counting techniques.

Viewfinder

The viewfinder has a field of 15 arcmin with an illuminated cross-wire and five concentric rings. Each ring is separated by 1 arcmin. The field is reversed, and with the photometer mounted with the eyepieces on the west side, north is right and east is down. The photometer can be turned in position angle.

Diaphragms

The diaphragm wheel has six positions corresponding to the following diameters:

Table 3.12: *0.5 m ESO Photometer: Diaphragm Sizes*

Position No.	1	2	3	4	5	6
Diam. arcsec.	10	15	21	30	40	80

Filter Wheel

The filter wheel has 12 positions and accepts filters up to 25.4 mm (=1 inch) diameter and up to 10 mm thick. The VA should inform ESO Staff through the request for observing time which filters she/he intends to use. When carrying out Strömgren and Johnson

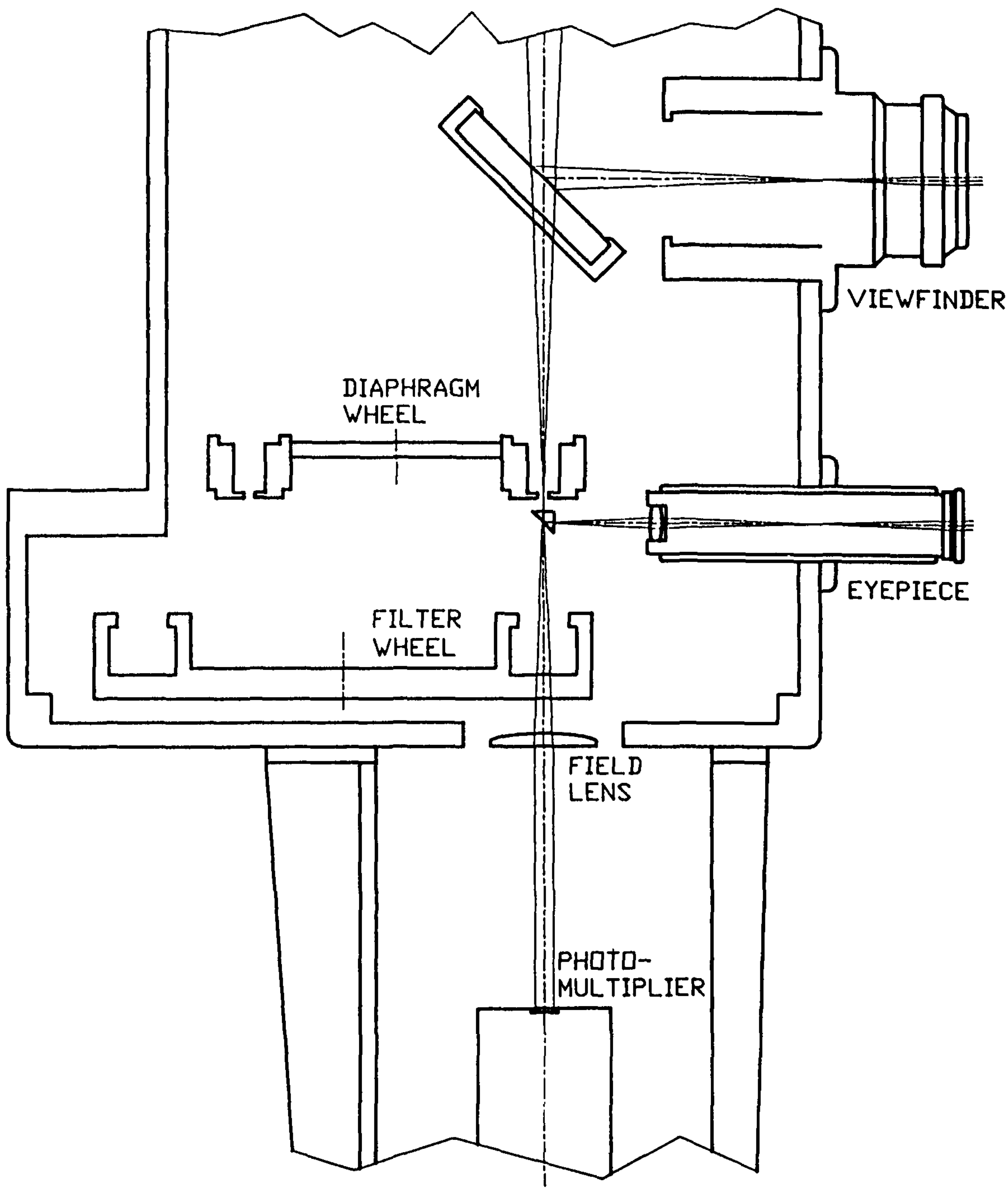

Figure 3.3: *The Single-channel Photometer at the ESO 0.5 m telescope*

Table 3.13: *0.5 m ESO Photometer: Standard Filter Wheel Positions for Blue-Sensitive Tube*

Position	Filter No.	Position	Filter No.
0	Hβ N 332	6	Dark
1	Hβ W 333	7	Dark
2	*u* 328	8	Dark
3	*v* 329	9	U 91
4	*b* 330	10	V 99
5	*y* 331	11	B 98

photometry, the filter sequence given in Table 3.13 is normally used (and is default in data acquisition and reduction programs).

The positions given in Table 3.14 are standard when working with the red-sensitive tubes (UBVRI).

Table 3.14: *0.5 m ESO Photometer: Standard Filter Wheel Positions for Red-Sensitive Tube*

Position	Filter No.	Position	Filter No.
0	B 289	6	Dark
1	U 556	7	Dark
2	Dark	8	Dark
3	Dark	9	I 292
4	Dark	10	R 291
5	Dark	11	V 290

If a different choice of filter allocation is made and if on-line magnitudes are required, consult the Operating Manual of the 0.5 m ESO telescope.

Photomultipliers

The photometer is constructed to allow fast daytime change-overs of photomultipliers and cold boxes. The observer may choose the photomultiplier most suitable for her/his programme from the available range of tubes, see Chapter 4.

Telescope and Photometer Control

Both the telescope and the photometer are controlled from a common terminal in the dome. Some photometer functions are controlled by means of a handset. The telescope control system (TCS) and data acquisition system (DAS) are implemented on HP 1000 computers. The TCS handles telescope pointing, telescope drive, dome movement, and coordinate files. The DAS controls the photometer setting, handles photometric data (e.g. to compute on-line magnitudes), and output devices. The DAS program is linked to the TCS program. The TCS system can store up to 200 star coordinates in its catalogue. Coordinates can be typed into the computer, or read in from magnetic tape, which can be prepared either at La Silla or elsewhere. For format see Operating Manual. The system will accept coordinates for any epoch. The photometer can be operated in the following modes:

Manual Mode: The photometer is operated conventionally with every command for filter wheel rotation and to start or stop integrations on each filter being initiated by the observer.

Automatic Mode: The observer can define a sequence of filter settings for object or sky measurements. For each filter, integration limits can be chosen by specifying the minimum and maximum number of integrations or by setting a standard deviation stop criterion (e.g. 0.5% accuracy). The observer subsequently only initiates the observing sequence, which is then performed under full computer control. If, for some filter setting, the mean deviation criterion is satisfied before the maximum number of integrations is reached, the photometer moves to the next filter. When necessary, the computer control can be overridden with the handset. Fixed integration times may be ensured by equaling the maximum and minimum number of integrations.

Repeat Mode: A given sequence of filter settings can be repeated automatically a number of times.

High Speed Mode: This is a free running mode where each basic integration of 1 second duration is written on tape and the mean is given at the end of the measuring sequence. It provides a convenient check on the quality of the night and may also be useful to detect the presence of spurious signals. Further details of the operation of the telescope and the photometer may be found in the Operating Manual.

Magnitude Limits and On-line Magnitudes

Objects should not be brighter than V = $5\overset{m}{.}5$ for UBV, V = $7\overset{m}{.}0$ for VRI, and V= $4\overset{m}{.}0$ for *uvby* photometry. This is to avoid damage to the multiplier. Stars down to V $\sim 14^m$ can be seen and centered in the diaphragm during moonless nights and under good seeing conditions. Even fainter stars may be seen with the help of an image intensifier mounted at the diaphragm viewer, upon request to ESO Staff.

By measuring one or several standard stars to determine the system zero-points, on-line magnitudes may be calculated using average values for extinction and transformation coefficients.

3.4.2 Transformations

Typical transformation equations for the different photometric systems in use at La Silla are given below. The rms residuals of the observations were less than 1% for BVRI and between 1% and 1.5% for U–B.

The Cousins UBV(RI)$_c$ System with the Quantacon Tube

The Quantacon RCA 31034 (C16817) tube was tested together with the standard Cousins filter-set ESO Nos. 556 (U), 289 (B), 290 (V), 291 (R) and 292 (I) during the three nights May 4, 5 and 6, 1990. The Quantacon was operated at 2000V and at a temperature of −75°C. 1mV discriminator setting. The dark-current was approximately 7 c/s.

A total of 87 measurements were made of standard stars of all colours and with V-magnitudes between 7.8 and 12.5, in the Cousins E- and F-regions. The following mean extinction coefficients were derived:

V: 0.124, B-V: 0.118, U-B: 0.188, V-R: 0.034, V-I: 0.073

The second order extinction coefficients in B-V and U-B were assumed to be −0.035 and 0.012 respectively, the rest were set to zero. The colour transformation coefficients (defined in the usual way) were:

V: -0.038, B-V: 1.067, U-B: 1.066 and -0.082, V-R: 1.043, V-I: 0.995

Typical count rates measured through a 21″ diaphragm are:

	V	B-V	U-B	V-R	V-I	U	B	V	R	I
			magnitudes					c/s		
E7-3	8.11	0.00	-0.56	0.01	0.03	28K	74K	94K	73K	48K
E6-7	8.78	0.12	0.10	0.07	0.15	8670	37K	51K	41K	29K
E5-34	8.53	1.52	1.85	0.82	1.56	740	13K	59K	92K	122K
E7-52	10.78	0.02	-0.40	0.03	0.04	2250	6500	8550	6700	4680
E6-61	10.15	1.24	1.17	0.65	1.22	450	4250	14K	19K	21K
E8-A	12.10	0.60	0.10	0.35	0.69	300	1230	2630	2720	2710
sky			typical			60	160	400	440	700

The Cousins UBV(RI)$_c$ System with the EMI 9658RA Tube

The red-sensitive EMI 9658RA (SN 10764) tube was tested during the two nights May 7 and 9, 1990. It was operated at −1350V and dry ice cooled to −70°C. 1mV discriminator setting. The same set of filters as for the Quantacon. 71 measurements of standard stars were made, and the following extinction coefficients derived:

V: 0.144, B-V: 0.119, U-B: 0.206, V-R: 0.037, V-I: 0.080

The colour transformation coefficients were:

V: -0.089, B-V: 1.097, U-B: 1.119 and -0.121, V-R: 1.051, V-I: 1.029

Typical count rates through a 21″ diaphragm are:

	V	B-V	U-B	V-R	V-I	U	B	V	R	I
			magnitudes					c/s		
E7-89	6.09	-0.06	-0.25	-0.02	-0.04	42K	184K	154K	72K	9200
E4-28	6.63	1.20	1.21	0.62	1.17	2680	40K	88K	72K	15K
E6-7	8.78	0.12	0.10	0.07	0.15	3000	15K	14K	7000	930
E5-34	8.53	1.52	1.85	0.82	1.56	280	5160	14K	14K	3450
E7-8	10.55	0.17	0.04	0.13	0.26	785	3470	3270	1680	240
E7-72	10.44	0.62	0.03	0.36	0.70	430	2210	3000	1900	340
E8-A	12.10	0.60	0.10	0.35	0.69	200	820	930	550	105
sky			typical			90	310	290	150	40

Due to the much higher count rates allowed for the EMI 9658 tube, much brighter stars can be measured with a resulting larger span in magnitude. The higher extinction coefficient in V is due to one of the nights being of doubtful photometric quality. The high U-B extinction is related to the transformation problem discussed below.

As can be seen, the transformation coefficients using the EMI 9658RA tube are slightly higher than those for the Quantacon, but the transformation to the Cousins system is still good in all colours except U-B. Rather large deviations from the standard values are found for very red and very blue stars. This situation can probably be improved substantially by breaking the transformation line for U-B into two (or three) parts as a function of B-V. Still, the situation should be investigated further. It is likely that the exact shape of the blue part of the spectral response curve of the EMI tube or the UG2 + BG39 combination is responsible.

The dead-time correction with this setup was found to be 53±2ns. For work on faint stars the Quantacon is preferable, note for example the high relative (and absolute) response in the R- and I-bands.

The Johnson UBV System with the EMI 9789QB Tube

Finally, the two nights May 14 and 15, 1990, were spent in testing the blue-sensitive EMI 9789QB (SN7194). The tube was used at –970V at ambient temperature. Again 1mV discriminator setting. The ESO Johnson UBV filters Nos. 91 (U), 98 (B), and 99 (V) were employed.

62 measurements of standard stars were made resulting in the following coefficients:

Extinction	:	V: 0.125, B-V: 0.133, U-B: 0.284
Transformation	:	V: 0.023, B-V: 0.964, U-B: 0.984 and –0.007

Typical count rates through a 21″ diaphragm are:

	V	B-V	U-B	U	B	V
		magnitudes			c/s	
E7-89	6.09	-0.06	-0.25	81K	233K	48K
E4-28	6.63	1.20	1.21	5420	55K	33K
E3-9	8.91	-0.04	-0.26	5880	17K	3590
E5-34	8.53	1.52	1.85	490	7590	5940
E7-8	10.55	0.17	0.04	1580	4340	990
E8-47	10.62	0.52	0.07	1150	3125	930
sky		typical		35	80	45

Again problems with the transformation to the standard system for the U-B colour were encountered, at least if a linear relation was assumed for the whole colour interval in B-V, i.e. from very blue to very red stars. As before, this can be resolved by splitting the transformation line in segments as function of B-V (or U-B).

The EMI 9789 can be used at very high count rates, at least up to 400K. Measured dead-time: 61 ± 2ns.

The Cousins UBV(RI)$_c$ System with the Hamamatsu R943-02 Tube

The Hamamatsu R943-02 tube (S/N EA4767) was in use at the 0.5m ESO during the nights May 16–20, 1990, for work in the Cousins UBV(RI)$_c$ system with the normal Cousins filter-set ESO Nos. 556(U), 289(B), 290(V), 291(R) and 292(I).

The tube was operated at −1850V and Peltier cooled to −35°C. 1mV discriminator setting. The dark-current was approximately 3 c/s.

A total of 88 measurements were made of 22 standard stars with V-magnitudes between 8.0 and 10.6, from the list of Graham (1982). Due to the nature of the observing programme, the B-V colours were restricted to values between +0.0 and +1.9.

The following mean extinction coefficients were derived:

V: 0.125, B-V: 0.130, U-B: 0.187, V-R: 0.035, V-I: 0.072

The second order extinction coefficients in B-V and U-B were assumed to be −0.035 and 0.012 respectively, the others zero. The colour transformation coefficients were found to be:

V: −0.027, B-V: 1.051, U-B: 1.041 and −0.081, V-R: 1.028, V-I: 0.973

Typical count rates through a 21″ diaphragm are:

	V	B-V	U-B	V-R	V-I	U	B	V	R	I
			magnitudes					c/s		
16-H	8.09	0.24	0.22	0.14	0.29	14K	70K	105K	90K	75K
98	8.82	1.61	1.95	0.89	1.73	500	12K	53K	88K	146K
8-M	9.22	0.04	0.03	0.01	0.03	7850	31K	38K	29K	21K
108	9.78	1.91	2.15	1.04	1.97	160	3680	21K	40K	73K
8-W	10.54	0.17	0.06	0.11	0.24	2200	8600	12K	9800	8400
sky			typical			30	80	200	350	700

The standard deviation of the U-B values is large and more or less a function of standard U-B itself. A linear relation for values between −0.1 and 2.0 will give residuals of up to 0.07 mag and can thus not be assumed. Again, the situation will improve considerably if the relation is split into two different linear ones as functions of U-B.

The same equipment was in use one year later. Reductions from six nights during this period show values very similar to those quoted above.

3.5 The Six-channel Photometer at 0.5m Danish telescope

3.5.1 Introduction

This photometer combines the capabilities of the previously available four-channel *uvby* and the two-channel Hβ photometers.

An extensive manual by P. Nørregaard (Oct. 1988) gives all details of how to run the telescope and the photometric acquisition system.

A schematic of the photometer is shown in Fig. 3.4 (See also R. Florentin Nielsen, 1983). Light first passes through (A), a rotating wheel which can be opened or can introduce a reference light source. The wheel (B) has three positions, open, closed, or neutral density filter. The wheel (C) contains entrance diaphragms and a V-shaped slit to enable automatic centering of a star in the diaphragm. A mirror (D) can be inserted into the beam to reflect light into the Hβ section. If Hβ is not in use, the light continues to the achromatic lens (E) (f/6, focal length 402mm) which collimates the light before it falls on the grating (F) (1200 lines mm^{-1}, blazed at 500 nm in 1st order). The light is then focused by the achromat onto a set of exit slots (G) which is curved to follow the focal plane of the lens (dispersion is $\simeq$ 2nm mm^{-1}) after which the light is reflected back by mirrors (H) and finally reaches the photomultipliers (K). The light is imaged by a Fabry lens (J) in front of each photomultiplier. The lens is combined with an interference filter which together with the exit slot defines the spectral passband of each channel. In the case of the *v* and *b* channels an extra neutral density filter can be introduced which has about 50% transmission. The photomultipliers used are all uncooled EMI 9789QA's with bialkali cathodes.

3.5.2 Reference Light Source

This is an H^3 (tritium) source which decays to He^3 emitting β-particles at 12KeV (also known as a β-light source). The β-particles strike a phosphor which produces a broad continuum emission spectrum. The source is completely safe to handle and in the event the glass envelope is broken (requiring severe mechanical shock), the only precaution necessary is to open the doors to ventilate the dome for a couple of hours. Due to the phosphor the light output will vary with temperature by $\pm 0.3\%$ /°C. Furthermore, the light output will decrease slightly faster than the predicted half life of the isotope. Thus, the count rate of the source can be expected to decrease by about 10% year^{-1}.

3.5.3 Neutral Density Filters

The transmission coefficients of the neutral density filters as measured on the 0.5 m Danish telescope, January 1985, for the six passbands are shown in Table 3.15.

These coefficients may change with time. Therefore, if a neutral density filter is used in connection with observations of primary standard stars, accurate transmission coefficients should be determined each period by observing stars of suitable magnitudes with and without the filter. As mentioned above, the two filters in front of the *v* and *b* channels have a transmission of about 50% and should likewise be calibrated if used.

Table 3.15: *0.5m Danish Six-channel Photometer: Neutral Density Filters*

Filter	*u*	*v*	*b*	*y*	HβN	HβW
Transmission	0.1002	0.0946	0.0918	0.0938	0.0926	0.0924

3.5.4 Entrance Diaphragms

Table 3.16: *0.5m Danish Six-channel Photometer: Diaphragm Sizes*

Position	0	1	2	3	4	5
Diameter (″)	240	35	*	17	13	7

*) Position No. 2 contains a V-shaped slit, 45″ long in the legs and 2″ wide. This slit is used for automatic centering of the star in the diaphragm.

3.5.5 Viewfinder

In the manual mode two eyepieces (L and M in Fig. 3.4) mounted one above the other give access to a large field view and a diaphragm view respectively. The large field contains an illuminated cross-hair and is approximately 13 arcmin in diameter. The edge or the interior of the diaphragm may be illuminated as well. Star down to V = 13 mag can be seen and centered in the diaphragm.

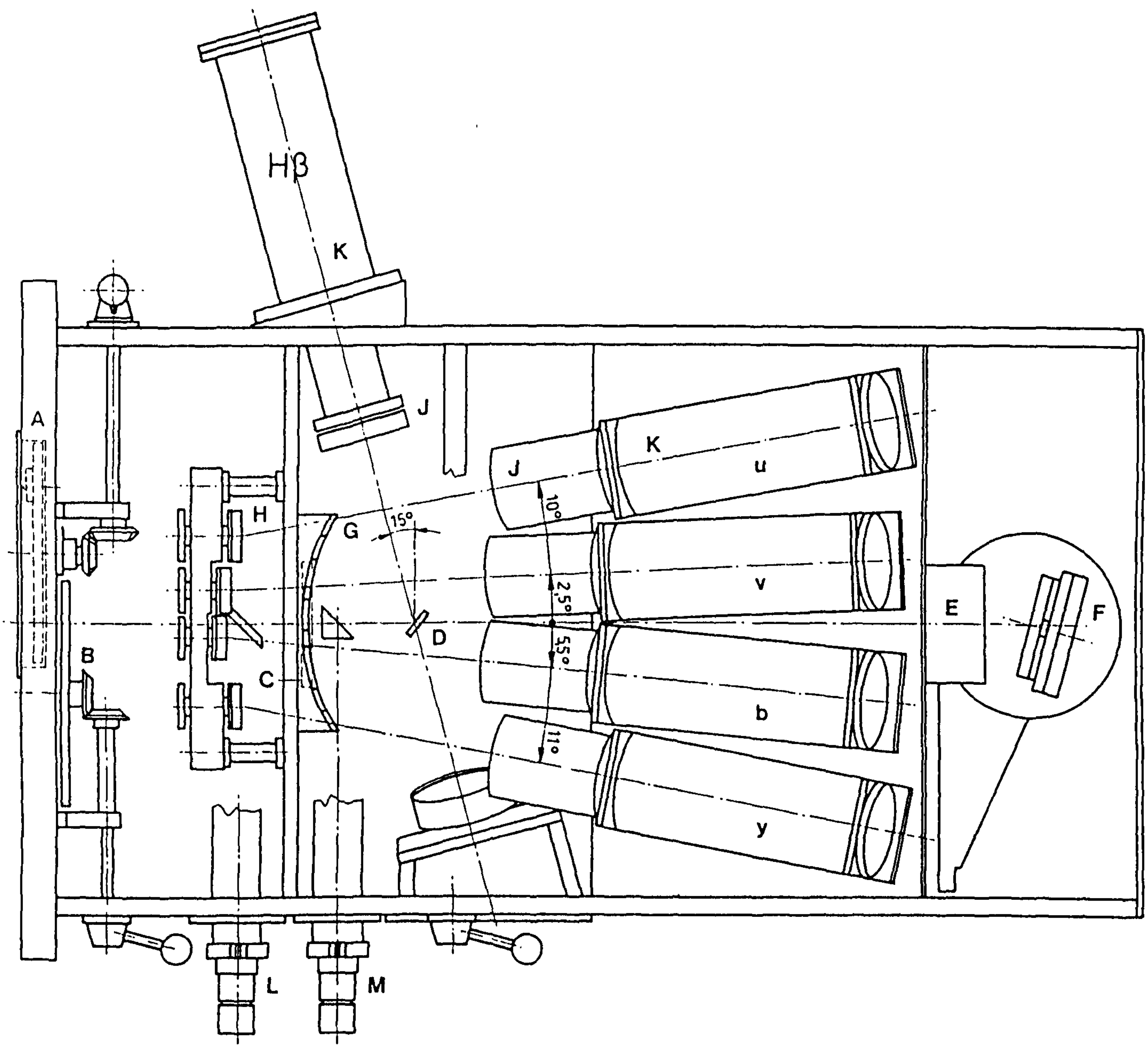

Figure 3.4: *The Six-channel Strömgren Spectrophotometer*

3.5.6 Adjustment of Grating Tilt

The grating angle may be changed by turning a micrometer screw, the position of which is shown on a meter. Half a turn of the meter — i.e. 0.1 units — corresponds to a wavelength shift of the spectrum of 1 nm. Increasing number of the meter corresponds to increasing wavelength for a given point on the exit-slot unit. The long wavelength edge of the *b*-slot (480.1 nm) happens to be very close to the wavelength of a strong Cd line at 479.99 nm. This can be used to find the correct setting of the grating. Illuminate the dome with a Cd spectral lamp. Wait five min for the lamp to stabilize, then point the telescope at the dome and measure the signal in the *b*-channel, while turning the grating meter in steps of 0.02 units from 0.6 to 0.9. Use the small diaphragm No. 5. As can be seen from the example in Fig. 3.5, the Cd line is centered on the edge of the *b*-slot for a meter position of 0.726. The correct setting 0.737, is then obtained by adding 0.011 units corresponding to the difference between 480.1 nm and 479.99 nm. Alternatively, the grating setting may be found by inserting the narrow Hδ slit in the *v*-band and scanning a star which has a suitable strong Hδ absorption. The minimum in the signal will then determine the grating setting. This method, however, requires good seeing and a very accurate tracking of the telescope. It is recommended to determine the grating setting every 2 or 3 months. Normally the setting remains the same for extended periods of time. The effect of nightly temperature variations is negligible small.

3.5.7 Optical Filters and Exit Slots

Table 3.17: *0.5m Danish Six-channel Photometer: Passbands*

Channel	λ eff	$\Delta\ \lambda$	Peak trans.	Slot-edges
u	350.5 nm	33 nm	76%	332.4–368.6 nm
v	411.0	17	83	400.6–422.2
b	468.5	18.3	89	457.2–480.1
y	548.8	23.5	90	534.6–563.6
HβN	486.4	3	70	
HβW	486.5	13.7	82	

The spectral response of the photometer is defined by the filters and — in the case of *uvby* — also by the exit-slots. The wavelengths of the slot edges corresponds to filter transmissions of about 20%. Table 3.17 gives effective wavelengths, half-widths, and peak transmissions of the filters as well as the wavelengths of the slot edges.

3.5.8 Photomultipliers

Table 3.18 provides information about the EMI 9789QA photomultipliers used in the 6-channel photometer.

The discriminators have been set at a level, where the dark count is less than about 20 counts s^{-1} at an ambient temperature of +5°C, and where the signal is a slowly

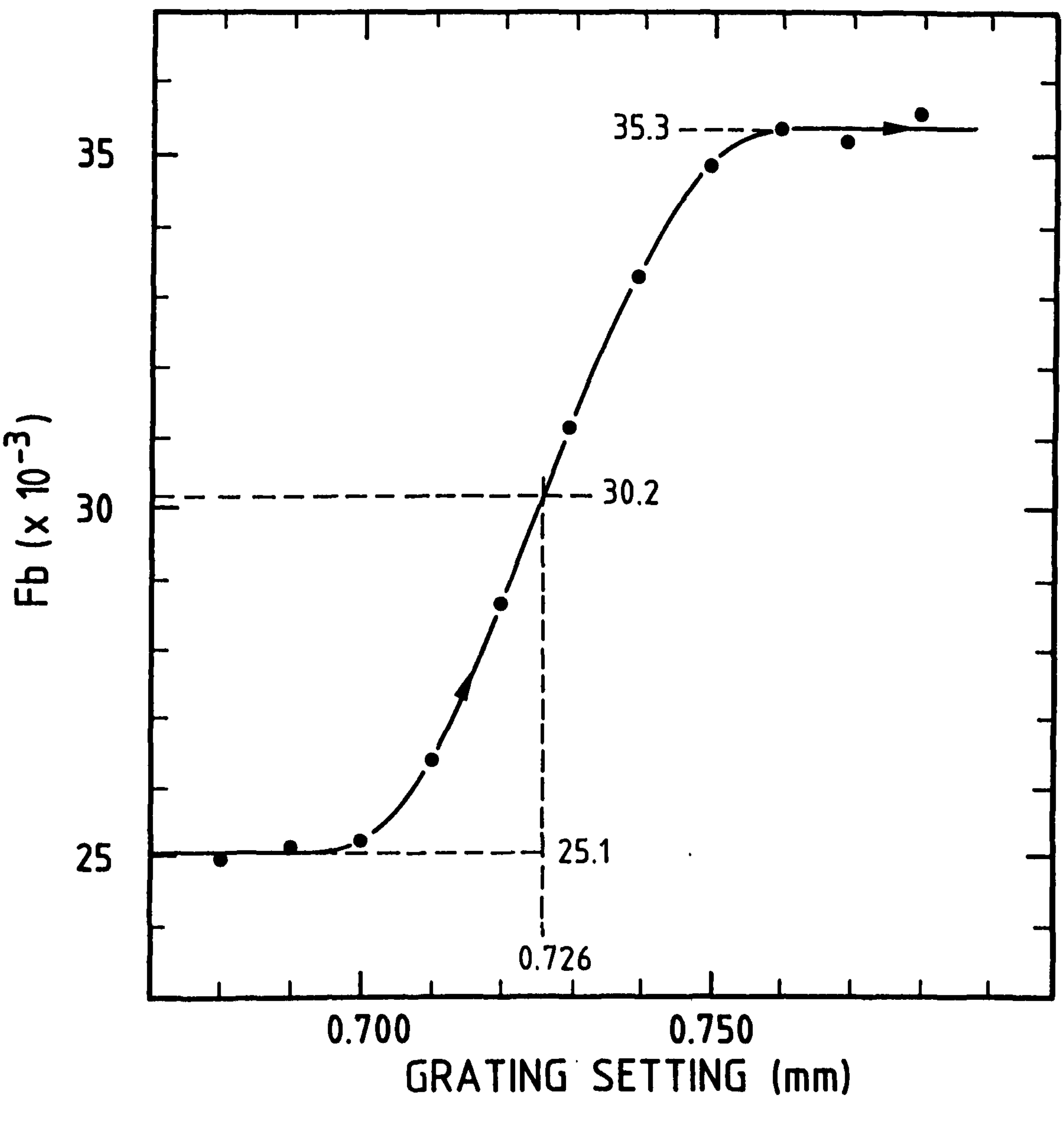

Figure 3.5: *Grating position determination of the six-channel spectrophotometers*

Table 3.18: *0.5m Danish Six-channel Photometer: Photomultiplier Characteristics*

Channel	Serial No.	Resistance in HV-distr.	Discrimi-nator	Dark at +5°C cs^{-1}	Reference Source Diaphragm #1 cs^{-1}
u	8319	240 KΩ	1.4	5	4200
v	8301	150 KΩ	1.3	2	3800
b	8302	120 KΩ	1.3	2	49000
y	8318	240 KΩ	1.4	10	43000
Hβ N	6719	0 KΩ	1.3	15	5700
Hβ W	8323	446 KΩ	1.3	3	5400
Spare	8300	0 KΩ			

Note: High-voltage HV = –1080 V

varying function of the discriminator setting. It should be noted that the dark count rate increases quite significantly when the ambient temperature rises above +10°C. At +15°C the dark count rates will be a factor 2–4 higher than the values listed in Table 3.18.

3.5.9 Count Rates

Typical count rates obtained on a moonless night (Nov. 1990) through a 17″ diaphragm are given in Table 3.19:

Table 3.19: *0.5m Danish Six-channel Photometer: Typical Count Rates*

	Sp	V	b-y	m_1	c_1	u	v	b	y
		magnitudes					c/s		
HD222368	F7V	4.13	0.332	0.161	0.397	50000	177500	227000	112300
HD16417	G5IV	5.79	0.412	0.205	0.386	9400	35200	49400	25800
HD212943	K0III	4.79	0.638	0.424	0.416	7800	43600	95000	61600
HD215724	F4IV	6.72	0.308	0.165	0.479	4940	18000	22300	10700
HD215257	G2	7.42	0.348	0.131	0.303	2750	8890	11200	5580
HD26297	G	7.49	0.732	0.243	0.618	700	3950	7740	5400
HD188510	G5V	8.84	0.411	0.113	0.152	690	2090	2790	1490
HD2796	G	8.51	0.536	0.071	0.502	650	2540	3560	2090
HD6268	G	8.12	0.598	0.082	0.540	775	3240	4880	3000
HD206178	F	9.82	0.244	0.222	0.142	350	1130	1330	640
Sky			typical			15	10	10	15

3.5.10 Colour Transformation and Extinction Coefficients

Preliminary values for the transformation coefficients were derived from observations of F and G stars during approximately 100 nights in 1985 to 1988:

$V(y)$: +0.021, b-y: 1.033, m_1: 0.940 and -0.041, c_1: 1.047 and +0.092

It is stressed that these coefficients are preliminary and valid only for the indicated range in spectral type. During the same period, the following mean extinction values were found:

$$V(y)\text{: } 0.150, \quad b\text{-}y\text{: } 0.041, \quad m_1\text{: } 0.071, \quad c_1\text{: } 0.125$$

3.5.11 Brightness Limits

Table 3.20: *0.5m Danish Six-channel Photometer: Magnitude Limits*

	uvby		Hβ
	Spectral types		
ND filter	OB	AFG	All
None	4.0	3.6	2.3
$v+b$	3.8	2.9	2.3
Entrance	1.5	1.1	-0.2
Both	1.3	0.4	-0.2

The count rate for the photomultipliers must not exceed 10^6 counts s^{-1}. Count rates higher than this may damage the photocathodes. In order to avoid large dead time corrections it is furthermore recommended that the count rate does not exceed about 500.000 counts s^{-1}. The corresponding limiting magnitudes for stars of different spectral types and for different combinations of neutral density filters are given in Table 3.20.

A practical lower magnitude limit is around $12^{m}_{\cdot}0$ in V.

3.5.12 Photon Counting System

A DIXI photon counting system incorporating pulse amplifiers/discriminators for the 6 channels handles the dataflow from the photomultipliers. Once every second all channels are sampled and the values displayed on the terminal screen.

3.5.13 Control System

The telescope, photometer, and dome are all controlled from a VMEsys 315 microcomputer based on a CPU-board with an M68000, 8MHz microprocessor and a memory board with 0.5Mb RAM. A 12Mb hard disc and a 655Kb floppy disc drive (not PC-compatible) are available for storing programs and data. Approximately half of the hard disc is free for user applications thus allowing, for example, very large coordinate files to be entered. The photometric measurements are stored during the night on the hard disc and may later be transferred to a floppy and magnetic tape. The coordinate files and the command files may be prepared using the system Versados editor. All details of how to run the MONI program are described in the SAT Manual by P. Nørregaard.

3.5.14 Observing Modes

A procedure to automatically center a star in the diaphragm has been developed for the 6-channel photometer. Position 2 of the diaphragm wheel is selected and the telescope is scanned in declination around the expected position of the star. When the star sweeps over the V-shaped slit it produces two intensity peaks. The position and internal distance of these peaks give the center offset which is then applied to the telescope. Since the MONI program is able to control this centering procedure as well as all other functions of the telescope and photometer, it is possible to run the system fully automatically. Stars down to at least V = 10.5 may be centered automatically during nights with no moon and good seeing. To utilize the good pointing of the telescope and to avoid misidentification of stars, an effort should be made to collect as accurate coordinates as possible for the stars to be observed. Proper motions should be specified when available. Close visual binaries will confuse the automatic centering. The telescope operation during a fully automatic run is controlled from a 'command file' which has to be prepared by the observer. This file must contain all particulars about the measurement such as what stars to observe and when, integration times, diaphragm size, *ubvy* or Hβ, etc. Coordinate files for standards and programme stars have to be prepared in advance. These files are utilized by the command file. The command file structure is very flexible and it is possible, after some experience has been gained, to build very sophisticated observing procedures. Some simple examples of command files may be found in the Manual by P. Nørregaard. It is however also possible to run the system in a more conventional 'manual' mode where all operations are defined and executed one after the other by the observer. It is recommended to do this at least for one night to get acquainted with the system before trying to work more automatically. Almost any mixture of manual and automatic mode may also be employed.

3.5.15 On-line Magnitudes

The MONI program calculates on-line magnitudes (or indices) based on values for the mean extinction coefficients, colour transformation terms and zero-points, provided by the observer. Very accurate magnitudes may be obtained in this way. The zero-points may be changed during the night if required from measurements of new standard stars.

Chapter 4

Photomultiplier Tubes

The characteristics of the photomultipliers available on La Silla are given in the table below. The cold boxes of the 1 m and 0.5 m ESO are interchangeable. The other telescopes use cold boxes with different field lenses.

	EMI 9789QA(B)	EMI 9658R	RCA3134A-02 QUANTACON	HAMAMATSU R943-02
Cathode type	Bialkali (K_2 Cs Sb)	S-20* Trialkali (Cs Sb)	Ga As:Cs-O	Ga As(Cs)
Effective cathode size (mm)	10 (diam)	42 (diam)	4×9	10×10
Window	Quartz	Prismatic	Fused silica	Fused silica
Dynode system	Venetian blind Cs Sb	Venetian blind Cs Sb	In-Line type Cu Be	In-Line type Cu BeO
No. of stages	13	11	11	10
Operating temperature (°C)	Ambient	−70	−30 to −45	−30 to −45
Cooling	None	Dry Ice	Peltier	Peltier
Supply Voltage (volts)	900 - 1200	1300 - 1500	1900 - 2000	1850 - 2000
Gain (typical)	25×10^6 at 1000V	0.6×10^6 at 1000V	1×10^6	5×10^5 at 2000V
Dark counts at op. temp. (cps)	5 - 40		20 - 50	5 - 10
Max count rate	500.000	500.000	50.000	50.000
Photometric system	uvbyHβ UBV	UBVRI	UBVRI	UBVRI
Telescope	3.6m, 1m, 0.5m ESO 0.5m Danish	3.6m, 1m 0.5m ESO	3.6m, 1m 0.5m ESO	3.6m, 1m 0.5m ESO

*) Corrugated window to increase red response
Q = Quartz window
A = Selection to customer's requirements e.g. low dark, high gain, etc.
B = Standard published specification
R = Selection for enhanced red sensitivity

Figure 4.1 displays the Quantum Efficiencies as a function of wavelength for the four types of photomultipliers.

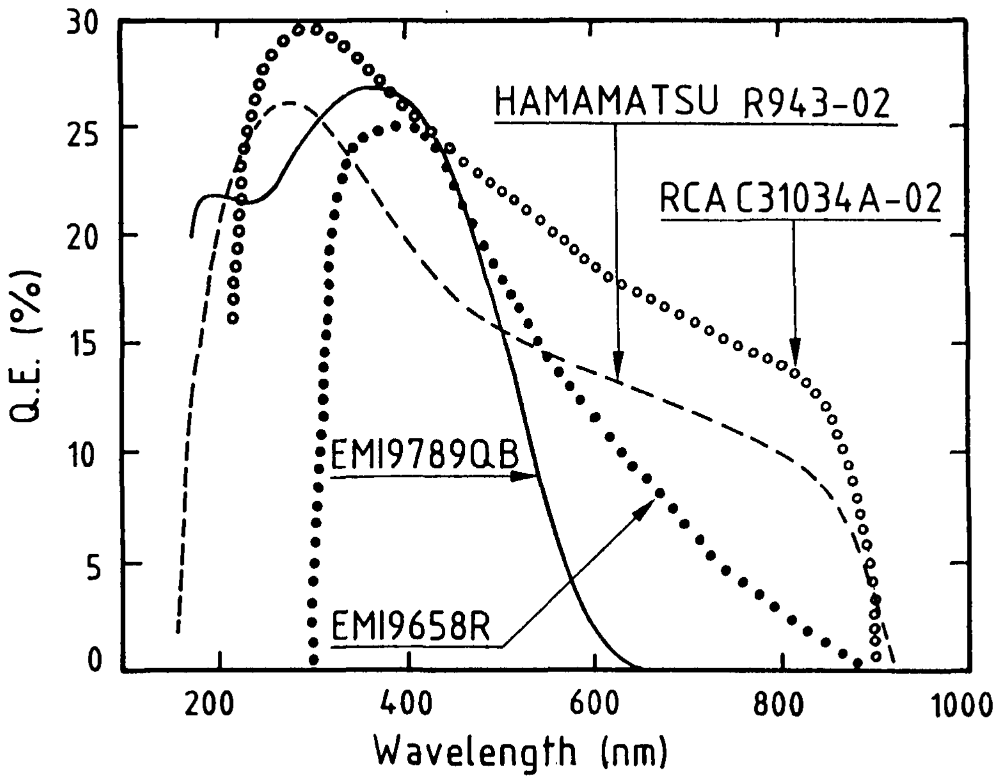

Figure 4.1: *Quantum Efficiencies for Photomultipliers used at La Silla*

Appendix A

Filter Transmission Curves

Figures A.1 to A.8 show the transmission curves for the various photometric systems in use at the La Silla ESO telescopes. Compare with the photomultiplier spectral response curves given in Figure 4.1. The accompanying tables give further filter details.

	U	B	V	Rc	Ic
Filter description	UG2 (1mm)+ $CuSO_4$(crystal) (5mm)	BG12(1mm)+ GG385(2mm)+ BG18(1mm)	GG495(2mm)+ BG18(1mm)	OG570(2mm)+ KG3(2mm)	RGN9 (3mm)
ESO #	624	275	276	277	278
Center wavel. Å	3523.0	4358.8	5405.7	6275.0	8818.7
Peak wavel. Å	3619.0	4434.4	5243.9	5936.3	7883.5
Bandwidth Å	753.3	984.6	1045.7	1224.7	3317.6
Peak trans. %	80.3	54.9	78.9	70.8	89.1
Optical thickness mm	~ 2.00	1.65	1.24	1.80	0.95
Mechanical thickness mm	~ 6.00	4.60	3.50	5.20	2.90
Comment	Red leak not detected				Red cut-off defined by tube

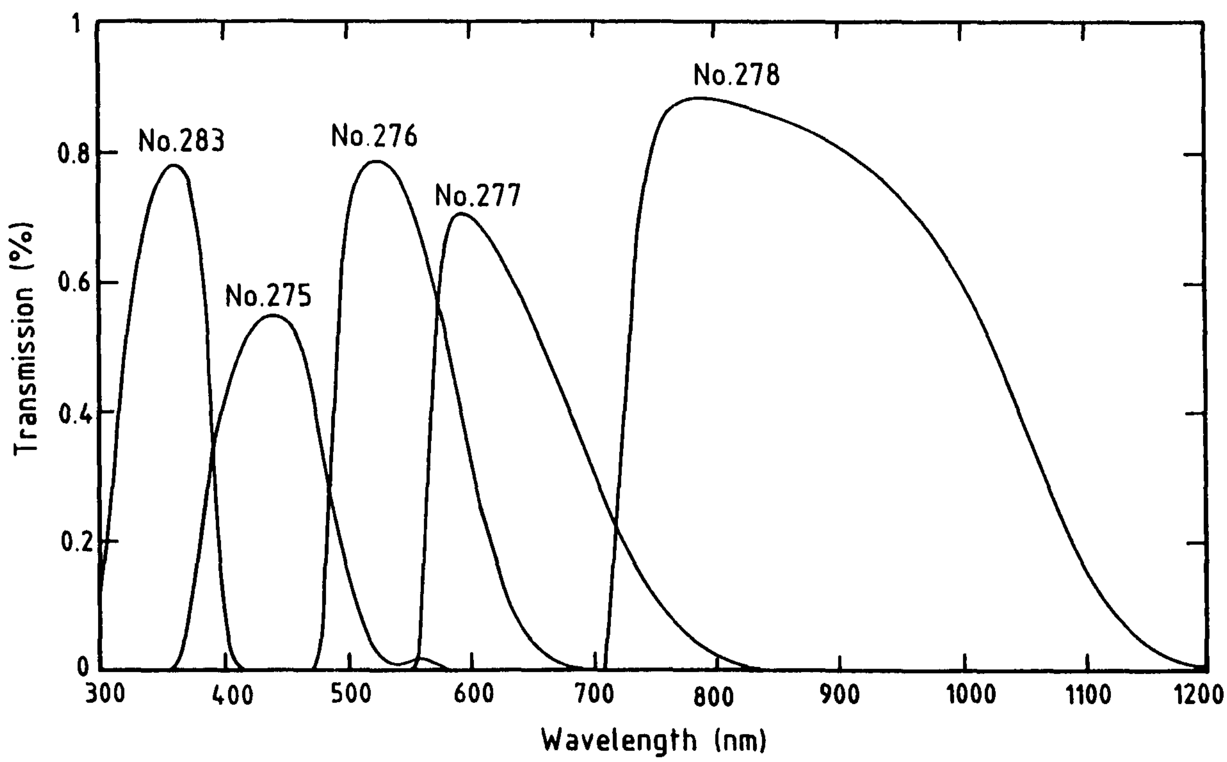

Figure A.1: *Transmission curves: 3.6m Cousins $UBV(RI)_c$ System*

	u	*v*	*b*	*y*	$H\beta N$	$H\beta W$
Filter description	UG11(8mm)+ WG3(1mm)	Interfer.	Interfer.	Interfer.	Interfer.	Interfer.
ESO #	310	311	312	313	314	315
Center wavel. Å	3502.6	4123.9	4678.4	5484.4	4869.0	4870.4
Peak wavel. Å	3492.7	4195.2	4650.6	5426.4	4868.0	4844.2
Bandwidth Å	322.1	192.7	167.0	214.1	27.7	143.6
Peak trans. %	43.4	45.5	59.2	63.2	51.2	61.8
Optical thickness (mm)	—	2.13	2.15	2.10	2.12	2.12
Mechanical thickness (mm)	9.90	6.10	6.10	6.10	6.10	7.00

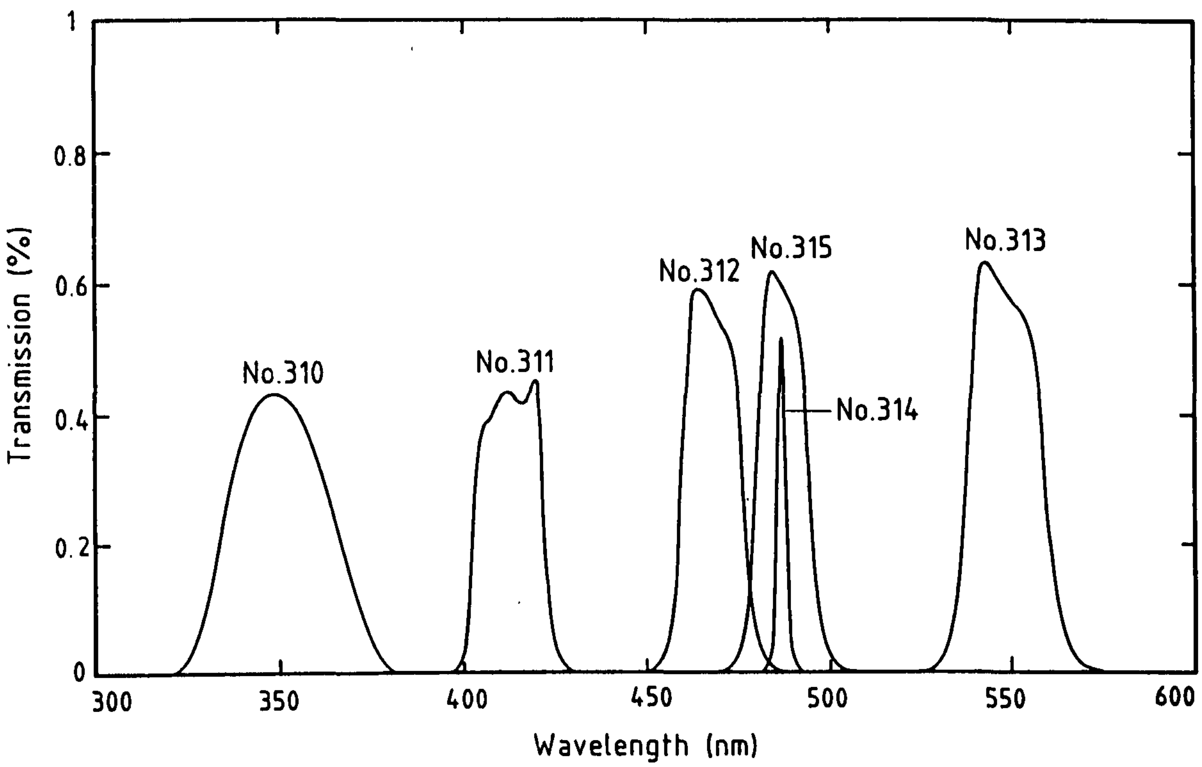

Figure A.2: *Transmission curves: 3.6m, Strömgren uvbyHβ system*

	U	B	V
Filter description	UG2(2mm)	BG12(1mm)+ GG385(2mm)	GG495(2mm)
ESO #	113	112	111
Center wavel. Å	3553.8	4392.9	5216.4
Peak wavel. Å	3605.0	4262.4	—
Bandwidth Å	591.1	1078.9	L.W.P.
Peak trans. %	64.1	77.2	92.8
Optical thickness mm	0.71	2.31	1.43
Mechanical thickness mm	2.00	6.70	4.00
Comment	Wide red leak	Wide red leak	Red limit by tube

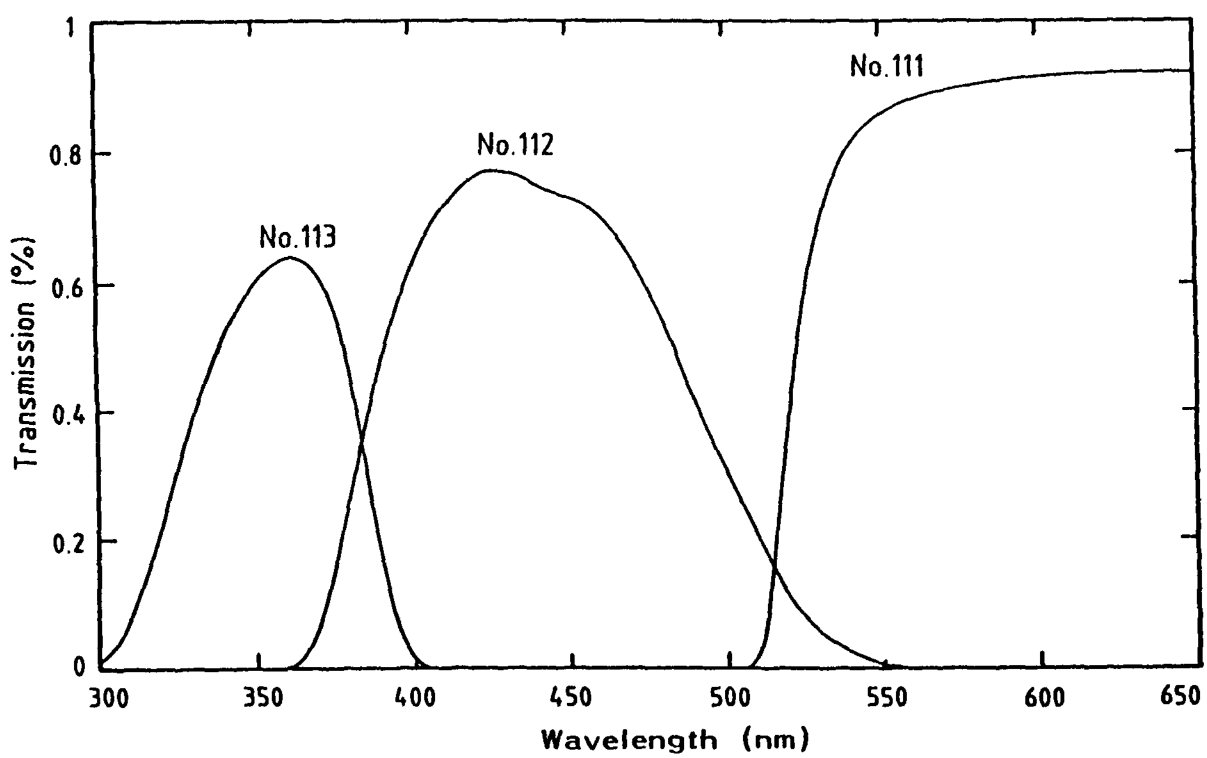

Figure A.3: *Transmission curves: 1m, Johnson UBV system*

	U	B	V	Rc	Ic
Filter description	UG2(1mm)+ CuS04(crystal)+ (5mm)	BG12(1mm)+ GG385(2mm)+ BG18(1mm)	GG495(2mm)+ BG18(1mm)	OG570(2mm)+ KG3(2mm)	RGN9 (3mm)
ESO #	283	284	285	286	287
Center wavel. Å	3528.7	4352.8	5397.9	6281.7	8796.6
Peak wavel. Å	3615.2	4400.4	5241.0	5944.0	7847.9
Bandwidth Å	752.3	984.7	1047.9	1218.8	3063.8
Peak trans. %	78.2	54.8	78.6	71.2	92.3
Optical thickness mm	2.07	1.65	1.21	2.82	1.09
Mechanical thick- ness mm	6.10	4.50	3.40	5.10	3.00
Comment	Red leak not detected				Red cut-off defined by tube

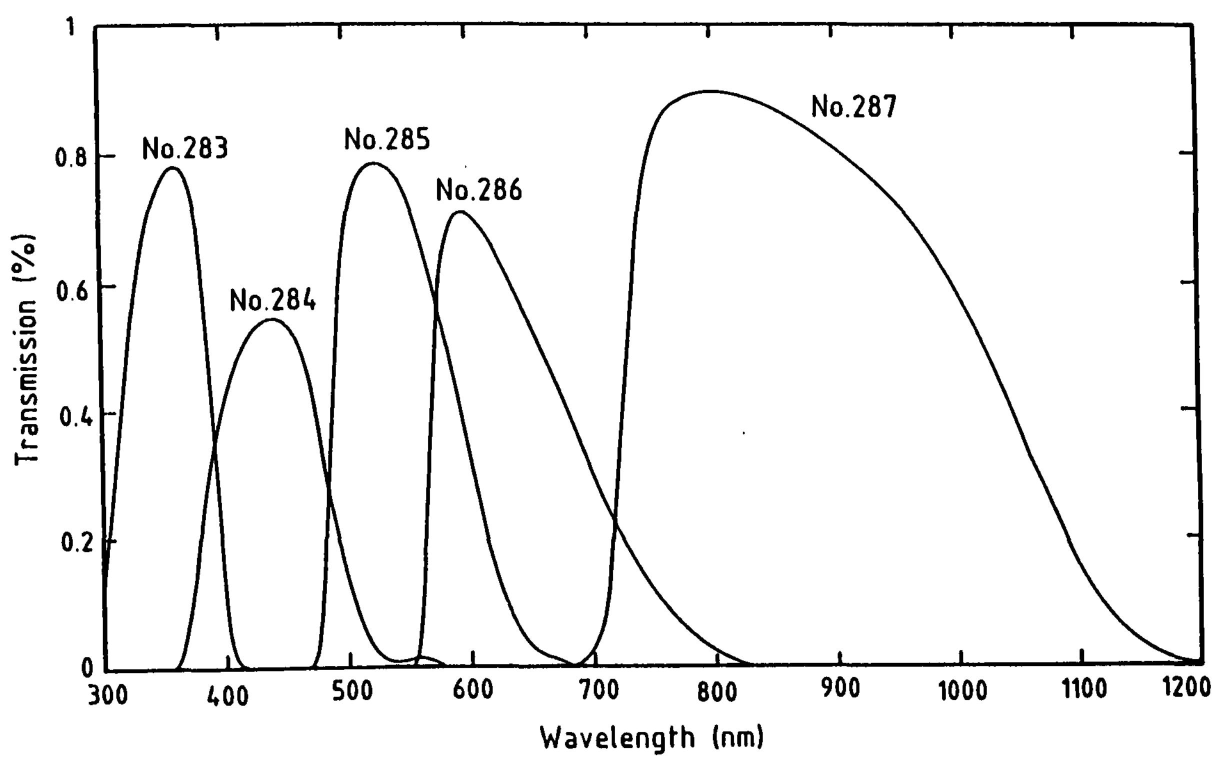

Figure A.4: *Transmission curves: 1m Cousins UBV(RI)$_c$ system*

	u	*v*	*b*	*y*	Hβ N	Hβ W
Filter description	UG11(8mm)+ WG3(1mm)	Interfer.	Interfer.	Interfer.	Interfer.	Interfer.
ESO #	322	323	324	325	326	327
Center wavel. Å	3501.1	4122.9	4676.4	5477.1	4867.0	4870.9
Peak wavel. Å	3493.7	4193.2	4637.7	5424.4	4867.0	4846.2
Bandwidth Å	321.1	192.7	167.0	213.2	27.7	144.6
Peak trans. %	44.1	45.6	58.7	63.3	53.4	62.0
Optical thickness (mm)	—	2.13	2.22	2.17	2.11	2.11
Mechanical thickness (mm)	8.90	6.10	6.30	6.20	5.90	5.90

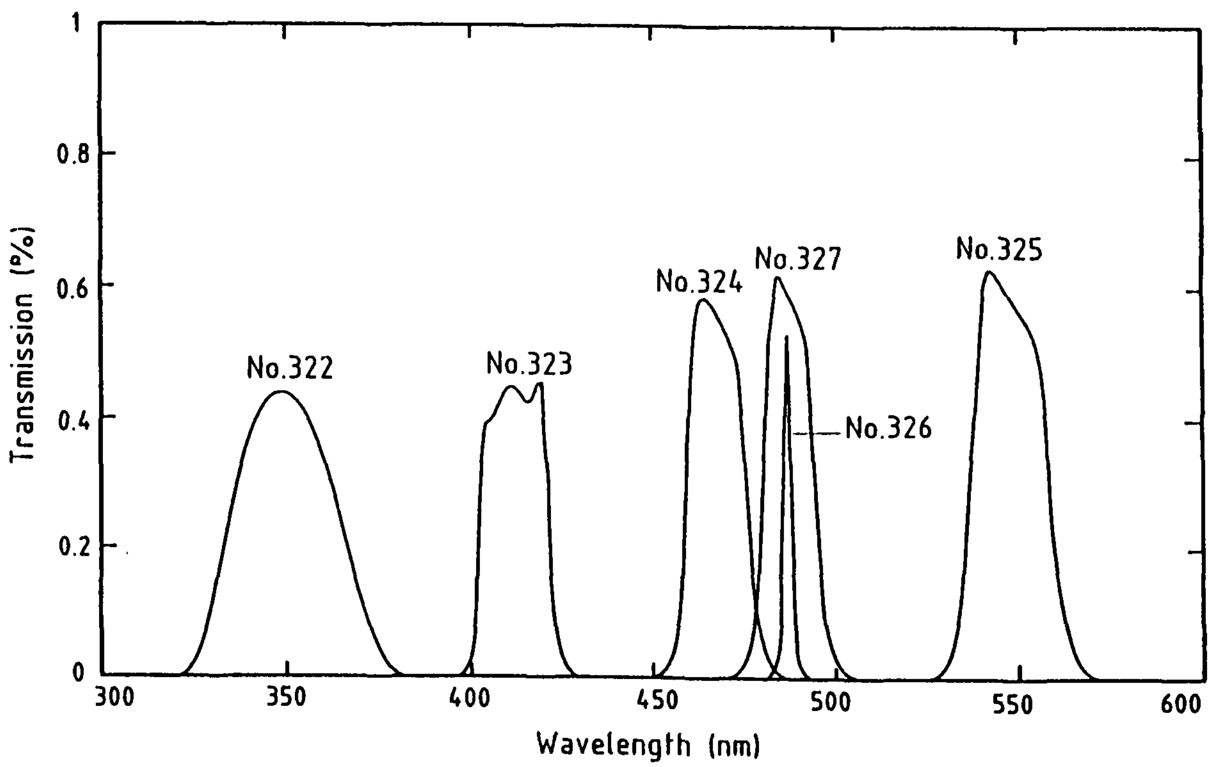

Figure A.5: *Transmission curves: 1m, Strömgren* uvby*Hβ system*

	U	B	V
Filter description	UG2(2mm)	BG12(1mm)+GG385(2mm)	GG495(2mm)
ESO #	91	98	99
Center wavel. Å	3207.0	~ 4450.0	5215.2
Peak wavel. Å	3247.0	~ 4300.0	—
Bandwidth Å	1369.2	~ 1100.0	L.W.P.
Peak trans. %	87.4	~ 78.0	91.0
Optical thickness mm	—	—	—
Mechanical thick-ness mm	—	—	4.00
Comment	Wide red leak at 6750. Blue limit by atmosphere	Wide red leak at 7300	Red cut-off defined by tube

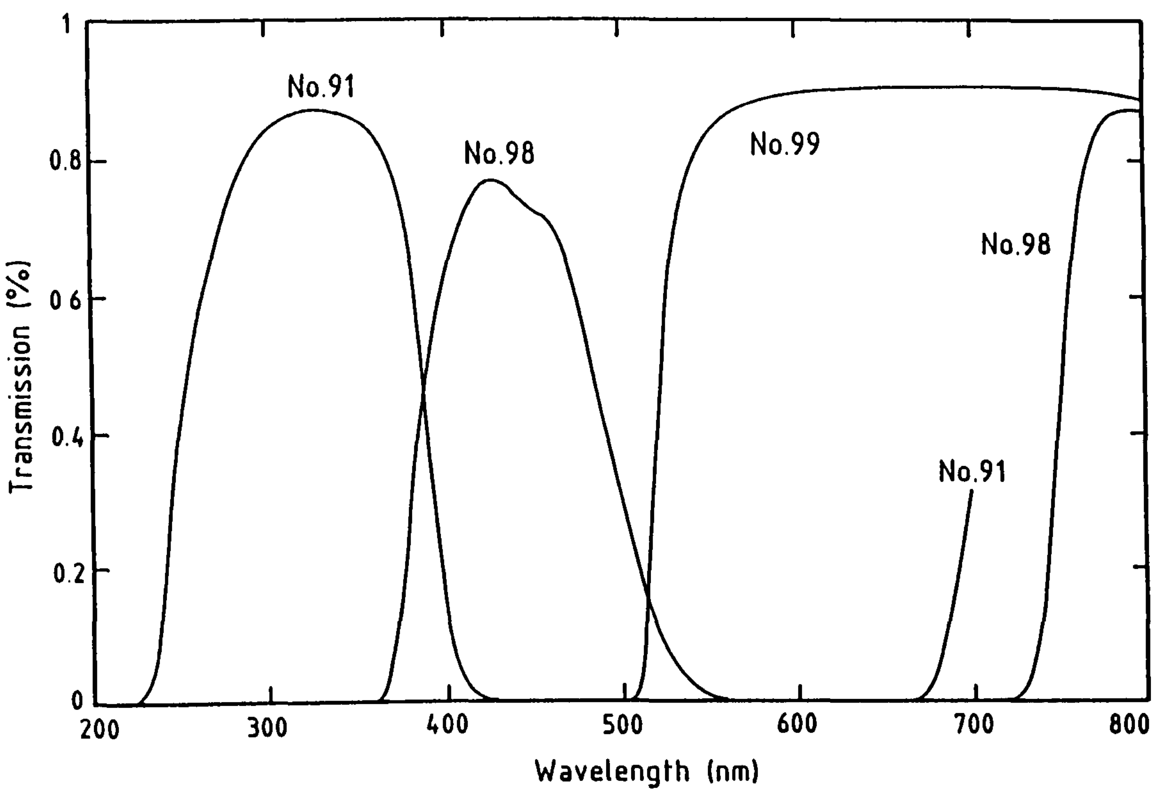

Figure A.6: *Transmission curves: 0.5m ESO, Johnson UBV system*

	U	B	V	Rc	Ic
Filter description	UG2(1mm)+ BG39(2mm)	BG12(1mm)+ GG385(2mm)+ BG18(1mm)	GG495(2mm)+ BG18(1mm)	OG570(2mm)+ KG3(2mm)	RGN9 (3mm)
ESO #	556	289	290	291	292
Center λ(Å)	3677.4	4358.9	5395.9	6290.4	8786.0
Peak λ(Å)	3703.1	4424.4	5227.2	5965.3	7519.3
Bandwidth (Å)	485.0	980.6	1040.1	1212.7	3002.2
Peak trans. (%)	55.8	54.8	78.1	71.3	94.7
Optical thickness mm	—	1.70	1.28	1.77	1.06
Mechanical thickness mm	—	4.70	3.60	5.00	3.00
Comment					Red cut-off defined by tube

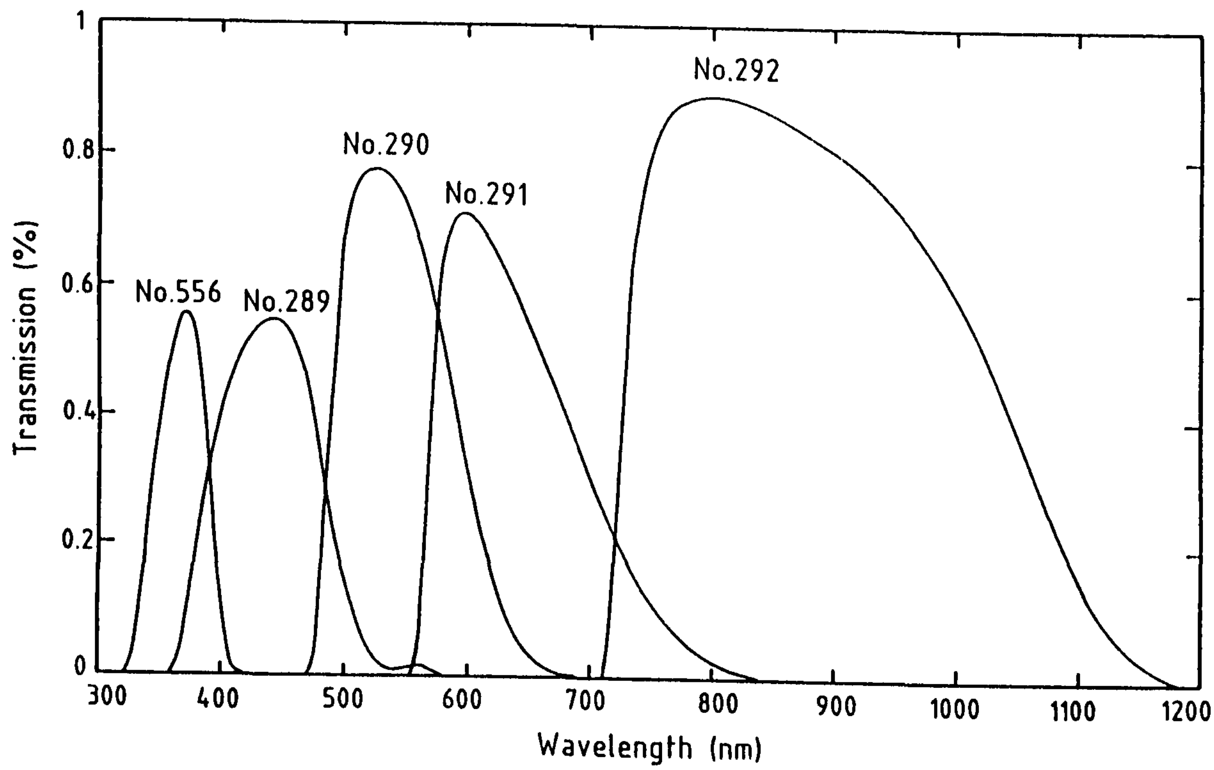

Figure A.7: *Transmission curves: 0.5m ESO, Cousins UBV(RI)$_c$ system*

	u	v	b	y	HβN	HβW
Filter description	UG11(8mm)+ WG3(1mm)	Interfer.	Interfer.	Interfer.	Interfer.	Interfer.
ESO #	328	329	330	331	332	333
Center wavel. Å	3504.2	4120.4	4676.2	5474.2	4866.5	4868.9
Peak wavel. Å	3495.7	4190.2	4641.5	5422.4	4867.0	4844.2
Bandwidth Å	319.1	191.7	167.0	213.2	26.7	142.6
Peak trans. %	43.4	45.7	59.6	63.0	53.2	62.9
Optical thickness (mm)	—	2.13	2.22	2.17	2.11	2.14
Mechanical thickness (mm)	8.90	6.00	6.20	6.10	5.90	6.00

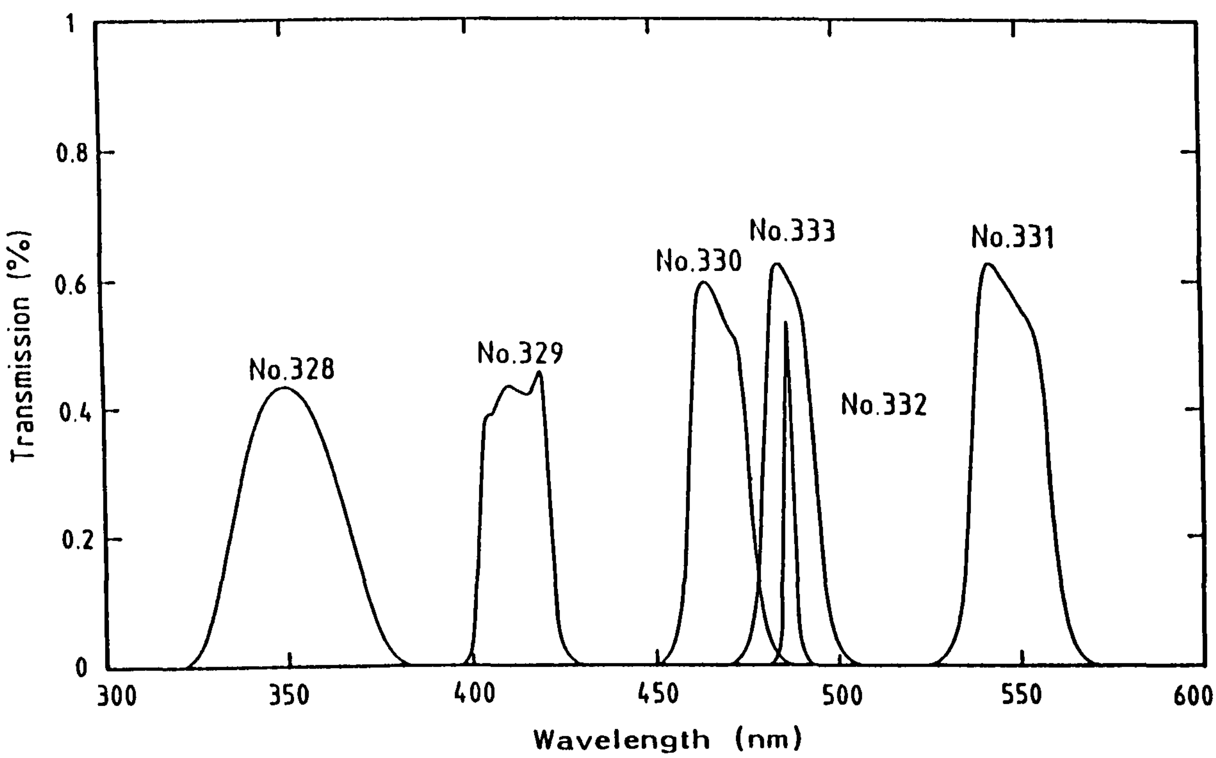

Figure A.8: *Transmission curves: 0.5m ESO, Strömgren uvbyHβ system*

Appendix B

Dead-time Determinations

The correlation between the true count rate N_t and the observed N_0 is described by the dead-time constant t_d according to the formula $N_t = N_0/(1 - N_0 t_d)$.

We have found the following setup very useful for accurate measurements of the dead-times. A Schott KL 1500 lamp with 5 neutral density filters was connected to the stabilized power line. A part of the inside of the dome was diffusely illuminated and the telescope brought to point to this area. Two nearly identical Strömgren *y* filters were installed in two filterwheel slots. To provide a fixed transmission difference between the two slots, one Kodak No. 96 neutral density filter with a nominal density of 1.0 was added to one of the slots and another with 0.1D to the other. This gives a fixes transmission ratio of approximately 0.13. The Kodak No. 96 is completely grey over the y-filter band-pass. By using different combinations of photometer diaphragms and the 5 lamp neutral density filters, it was possible to measure the intensity ratio between the slots (y+1.0D/y+0.1D) over a considerable range in count-rate. Due to loss of counts at higher count-rates these ratios will increase slightly as a function of the difference between the counts obtained through the lighter slot and those observed through the darker one: (y+0.1D)-(y+1.0D).

If the ratio is plotted as a function of this difference, the dead-time t_d can be found as the slope of a line fitted through the points divided by the intercept by this line with the Y-axis.

Using count-rates (for the lighter density filter slot y + 0.1D) between approximately 100.000 and 500.000 for the EMI tubes, we were able to determine the dead-time corrections given in previous sections. The errors should be of the order of a few nanoseconds.

When the method above was used (with much lower count-rates) to test the more sensitive Hamamatsu and Quantacon tubes, no meaningful results were obtained. If anything, the results may have pointed to negative dead-time constants. However, since these tubes are meant to be used only for low count-rates the dead-time corrections are less significant and should amount to only a few thousands of a magnitude at most.

Tables B.1 and B.2 give the dead time corrections for the six channel photometers at the D1.5m and D0.5m telescopes.

Table B.1: *1.5m Danish Six-channel Photometer: Dead Time Constants*

Band	Dead time (10^{-9}s)
u	90 ± 10
v	85 ± 8
b	85 ± 10
y	80 ± 10
Hβ N	90 ± 20
Hβ W	90 ± 20

Table B.2: *0.5m Danish Six-channel Photometer: Dead Time Constants*

Band	Dead Time (10^{-9}s)
u	72 ± 15
v	95 ± 5
b	88 ± 10
y	73 ± 15
Hβ N	71 ± 10
Hβ W	89 ± 10