EUROPEAN SOUTHERN OBSERVATORY

THE ESO USERS MANUAL

1993

The ESO
Users Manual

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Chapter 1

The European Southern Observatory: an introduction

1.1 Introduction

ESO is a European intergovernmental organization for astronomical research. It provides a range of telescopes and associated instruments for European astronomers to study that part of the Universe seen from the southern hemisphere.

The ESO Observatory is at La Silla in the Atacama desert in Chile.

Latitude	Longitude	Altitude
29°15′S	70°44′W	2400 m

Since September 1980, the European headquarters of ESO have been in Garching near Munich (Germany).

Site testing for a southern hemisphere observatory was carried out both in South America and South Africa. On the basis of these tests, the La Silla site 600 km north of Santiago, in Chile, was selected.

The convention establishing the European Southern Observatory was signed by the five founding member countries: Belgium, France, Germany, Netherlands and Sweden, in Paris on 5 October 1962. It came into effect in 1964. The basic agreement with the Chilean government was signed in November 1963, and on 25 March, 1969, President Eduardo Frei inaugurated the Observatory. In 1967 Denmark joined ESO and in 1982, Italy and Switzerland also joined.

The eight Member States exercise control over the Organization through a Council composed of two delegates per Member State which is advised by a Finance Committee consisting of one delegate per Member State. Within the framework agreed by the Council, complete responsibility for management and day-to-day operation is vested in a Director General, appointed for five year terms. Three committees advise the Director General:

the Scientific and Technical Committee (STC), the Observing Programmes Committee (OPC), and the Users Committee (UC).

Member States have equal voting rights, but contribute to the budget in proportion to their net GNP. However, the maximum contribution from any one State is not to exceed 27% of the total budget. The annual contributions from Member States amount in total to approximately 106 million DM (1991).

The OPC, composed largely of scientists working within the Member States, evaluates proposals for observing time on the basis of scientific merit.

The UC is composed of eight members, one from each of the member countries, which are appointed by the Director General from among the frequent, experienced Visiting Astronomers (VA).

The UC advises the Director General on matters pertaining to the functioning of the La Silla observatory from the point of view of the Visiting Astronomers. The UC also advises the Director General on matters related to the support given by the both for Remote Control and Data Reduction.

The STC is composed of 10 scientists from the member countries. They are appointed by the Council. This committee advises the Director General and the Council on scientific and instrumentation policy, and participates actively in the definition of scientific and instrumental programmes. It further advises Council and the Finance Committee on budgetary matters related to instrumentation.

1.2 Addresses, phone, FAX, telex, and e-mail

ESO European headquarters

Karl-Schwarzschild-Straße 2
D-85748 Garching bei München
Germany
Telephone: (089) 32006-0
Director General -226
Visiting Astronomers Section -223
Astronomy Group -229
Image Processing -230
Sky Atlas Laboratory -276
Technology Division -258
Administration -221
Telex: 05 282 820 eo d.
FAX: 89 3202362
Telegrams: EURASTRO Garching bei München
E-mail: `ESOMC1::VISAS(SPAN)`; `VISAS@DGAES051` (EARN/BITNET); `@eso.org` (Internet); `eso.uucp` (UUCP).

La Silla Observatory

c/o Alonso de Córdova 3107
Vitacura
Casilla 19001

Santiago 19, Chile
Telephones: Santiago 6988757 or 6993425*
La Serena 224527 or 224932
Telex: 240881 ESOGO CL
FAX: 02-6954263 (direct 24h link)
E-mail Address: lasilla@lw0.ls.eso.org

ESO Office in Santiago
Alonso de Córdova 3107
Casilla 19001
Santiago 19, Chile
Telephone: 02-2285006
Telex: 240853 ESOGO CL
FAX: 02-2285132
Telegrams: ESOSER Santiago de Chile

ESO Office in La Serena
Recinto del Terminal de Buses
Avenida El Santo S/N
La Serena, Chile
Telephone: 051-225387 (only Spanish spoken)
Telegrams: ESOSER La Serena

ESO guesthouse in La Serena
Juan Cisternas 2020
Casilla 567
Telephone: 051-224443 (only Spanish spoken)
La Serena, Chile
Telegrams: ESOSER La Serena

ESO guesthouse in Santiago
Gustavo Adolfo 4634
Santiago, Chile
Telephone: 02-2084254
02-2289333

ESO Office in Antofagasta
Balmaceda 2536, Of. 504.
Antofagasta, Chile
Telephone: 055-260032 or 055-260048
Telefax: 055-260081
Telex: 225222 ESOGO CL
Cerro Paranal: 055-242680

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* From 18:30 to 7:55 (LT) linked to the NTT control room.

1.3 ESO in Chile – Santiago, La Serena and La Silla

1.3.1 Introduction

The following descriptions of expense considerations apply only to Visiting Astronomers (VAs) from Member States. Expense considerations for VAs from non-Member States must be discussed individually with the ESO Visiting Astronomer Service.

1.3.2 Charges and allowances

ESO financial support is granted generally only to astronomers from institutions in the ESO Member States. This includes:

1. Round trip airfare and ground transport.
2. Free board and lodging in the guesthouse in Santiago for up to four (4) days and at La Silla for the observing period and up to seven (7) additional days.

Outside this period, and in cases when free board, lodging and travel are not provided by ESO, the charges to VAs are as follows:

Lodging in the ESO guesthouse (bed and breakfast)	:	DM	52.-
Main meal in the ESO guesthouse	:	DM	13.-
Per 24-hour day at La Silla	:	DM	51.30
Air transfer to/from La Silla (one way)	:	DM	170.-
Surface transfer to/from La Silla (one way)	:	DM	50.-
Airport taxi in Santiago (approximately)	:	DM	23.-

In the event that no room is available in the guesthouse, or when an overnight stay is necessary on the way to or from La Silla, ESO supported VAs are paid a daily allowance.

The VA should bring sufficient funds (preferably traveller's cheques in US $ or currencies of ESO Member States) to cover expenses likely to be incurred before, during, and after travel to/in Chile. These cheques may be changed by ESO (cashiers at La Silla, the Santiago office or the guesthouse) into Chilean pesos. US $ traveller's cheques are also accepted by any Chilean bank.

ESO cannot supply cash in hard currency or change cheques or give allowances in hard currency.

1.3.3 Santiago

In Santiago accommodation is either in the ESO guesthouse or one of the principal hotels in town. The latter are used only when the guesthouse is full. Hotel reservations are made by the ESO office in Santiago. Three meals per day as well as afternoon tea are served at the guesthouse. For VAs lodged in hotels, a daily allowance is paid.

On arrival visitors will be given an information package containing the necessary maps of Santiago, etc.

1.3.4 La Silla

At La Silla, there is a central building, the 'hotel', with a dining room, lounges, dormitories, lobby, and mail boxes (see map of La Silla, end of this section). The cinema, video and reading rooms are also located in the hotel. Nearby are additional associated dormitories. The hotel serves as a central meeting place and communication centre. On arrival at La Silla, the VA will be contacted by the lodging staff and assigned a single study bedroom in one of the dormitories. Room number assignments and room telephone numbers are posted in the hotel lobby. Each dormitory is furnished with the following:

- Observing clothes and flashlight (to be returned to the dormitory cleaner on the day of departure).
- Private shower and toilet facilities.
- Clean towels and soap.
- Leaflet concerning domestic arrangements within the observatory.
- Internal telephone and guide.
- Electric outlets of 220V, 50 Hz.
- ESO stationery and post cards.

Besides normal meal times, which are posted in the hotel dining room, the astronomer can order a night lunch, consisting of a hot or cold meal or sandwiches which are delivered to the telescope. Forms to order meals are available in the dining room.

1.3.5 Mail and telex

Incoming mail can be found in the mail boxes sorted by room number at the internal entrance to the dining room. Mail via the "Diplo Bag Garching" arrives at La Silla on Mondays and has to be sent to Garching, care of the Visiting Astronomers Section.

Outgoing mail, except mail to the La Serena area, may be posted in one of the yellow boxes found at the hotel entrance or on the ground floor of the Astronomy and Administration building. The "Diplo Bag Garching" leaves La Silla on Thursdays at 15.30 hours.

In compliance with international agreements, VAs are only allowed to use the "Diplo Bag Garching" for sending scientific material, such as magnetic tapes, photographic plates or letters. No personal effects can be sent with it, and ESO reserves the right to open and check all mail and parcels.

La Serena mail must be placed in the mail box at the internal entrance to the dining room.

Chilean and German stamps (for mail to Europe via the Garching bag) as well as ESO post cards may be purchased from the communications office between 14:00 and 17.00 hours.

Telex and FAX may be sent from the communications office in the Astronomy and Administration building (ground floor). Indicate which telex/FAX are official and which private; private telex/FAX will be charged to the VA's personal account. Incoming telex/FAX will be placed in the individual mail boxes.

1.3.6 Telephone

- **Local calls** — public phone calls may be made from one of the three phone booths in the hotel basement, or directly from the astronomy secretary's office in the Astronomy and Administration building between 08.00 and 18.30 hours. After working hours calls may be made directly to La Serena or to Santiago from the phone booths. An automatic timer limits these calls to five minutes.

- **Long distance** — Long distance calls between 08.00 and 18.30 hours can be arranged through dialing 4215, for the ESO communications office. During weekends, the astronomy secretary may also be asked for help. From midnight till 8:00 AM, code 91 in the hotel basement phone booth gives dialing tone for long distance calls.

Register all long distance calls in the forms found in the telephone booths in the hotel and the astronomy secretary's office. Unless formally declared official, calls will be charged to the VA's personal account.

- **Internal phone system** — This system provides communication within the La Silla site only. Note that all numbers begin with "4".

- **Pagers** — Some key persons at La Silla carry pagers. These can be called by dialing 93, waiting for a single "beep" then dialing the appropriate 2-digit number of the required person. After a series of beeps, speak your extension number clearly and slowly several times, then hang up. The person will then phone you.

To call La Silla from La Serena, dial "224527" or "224932"; to call La Silla from Santiago dial "6988757" or "6993425". Urgent calls during night time should be made to the latter number.

1.3.7 Electronic mail

The VAX 11/750 and SUN computers are connected by satellite link to the MC1 VAX or ns1 SUN node in Garching. Electronic mail can be sent and received through this network. E-mail must be sent to `ESOMC1::LASILLA` (span) or `LASILLA@DGAES051` (bitnet) or `lasilla@ls.eso.org` (Internet) from where it will be automatically sent to La Silla. On La Silla e-mail for the VAX or SUN arrives in the `LASILLA` account. For the password to this account, contact the La Silla system manager or the astronomy secretary.

1.3.8 Travel reservations at La Silla

Travel reservations, confirmations, or changes can be made through the communications office while on La Silla.

1.3.9 Medical facilities

A limited medical service is permanently available on La Silla; however, astronomers should bring along items such as: anti-sunburn lotions, creams, cocoa butter sticks to deal with the possible effects of low humidity, and medication for stomach upsets.

If serious problems arise or accidents occur, transportation to a hospital is immediately available and all necessary measures will be taken by ESO.

Note:

> *VAs must be free from chronic diseases and illness which may require specialized treatment and should be medically fit to work at an altitude of 2400 m.*

1.3.10 Insurance

Insurance coverage is as follows:

In case of death	:	DM	125,000.-
In case of permanent total disability	:	DM	250,000.-
Medical expenses	:	DM	10,000/year.

This insurance takes effect following the start of the travel 48 hours prior to the planned arrival in Chile and expires 48 hours after departure from Chile, unless delays are incurred by circumstances beyond the control of the traveller. Reimbursement of medical expenses is only possible on presentation of a certificate issued by the attending physician.

ESO does not insure any personal effects during the observing mission. In case any equipment to be used for the execution of an observing programme is carried in hand luggage, the VA should inform the VAs' office in Garching not later than 4 weeks prior to the journey.

1.3.11 Entertainment

At La Silla, the VA will find available:

- Reading room — containing fiction books, magazines, European and local newspapers and publications, in the hotel basement.

- Movies — commercial and cultural twice a week at 20.00 hours in the hotel theatre. Titles are posted.
- TV and VHS video; pool table in the clubhouse; table tennis, weights room and gymnasium in the sports hall, where tennis, volleyball and indoor football can also be played.
- Playing cards and games — may be borrowed from the communications office.

1.4 Regulations for visiting astronomers in Chile

1.4.1 General rules

VAs are astronomers on mission to ESO establishments in Chile for the purpose of executing scientific programmes approved by the ESO Directorate. On acceptance of allocated observing time, it is implicitly understood that the VA has accepted the following regulations:

1. While in Chile, VAs are subject to the authority of the ESO Directorate.
2. VAs must refrain from acts prejudicial to ESO under the convention between Chile and ESO. They shall refrain from public political declarations or activities. They shall not sell anything brought by them to Chile.
3. VAs execute the programmes accepted by ESO, deviating from these only under exceptional circumstances. The ESO head of astronomy in Chile or the Visiting Astronomers Section in Garching are to be informed of all substantial modifications.
4. VAs should deliver to the Astronomy Office, a brief report upon termination of their mission in Chile (report forms are available in the astronomy lounge, hotel upper floor).
5. Before leaving Chile, VAs shall settle their personal accounts with the administration.
6. All observational data obtained with the ESO telescopes and secured either on photographic plates or magnetic tapes, remain the property of ESO. The Visiting Astronomer may take these documents elsewhere for analysis, following which they are to be returned to the Visiting Astronomers Section - Garching.

1.4.2 Credit statement

Publications based on observations collected at the ESO observatory should bear on the first page the footnote *Based on observations made at the European Southern Observatory, La Silla, Chile.*

1.5 Application for use of ESO telescopes

1.5.1 Introduction

Telescope time is allocated twice a year. Applications may be submitted for use of the 3.6 m, 3.5 m NTT, 2.2 m, 1.5 m ESO, 1.4 m CAT, 1 m, 1 m Schmidt, and 0.5 m ESO telescopes. In addition VAs have access to the SEST, 1.5 m Danish, the 0.9 m Dutch, and the 0.5 m Danish telescopes. Observers have to give precedence to all engineering/maintenance work and should assist the technical staff whenever necessary. Observers may also be asked to observe or to let staff astronomers observe targets of opportunity.

The NTT with EMMI/SUSI and the CAT can be used under remote control from Garching (section 1.8).

Programmes for VAs on the Schmidt are normally conducted by ESO staff.

Note:

You are strongly urged, before writing proposals, to read the relevant sections of this manual.

Observing time is split into periods of six months running from 1 April to 1 October, and from 1 October to 1 April. Submission deadlines are the preceding 1 October and 1 April, respectively.

Note:

Applications are accepted only if received prior to the submission deadline and when submitted on the latest version of the official application forms.

1.5.2 Address for submitting proposals

Official application forms can be obtained from and should be sent to:

Visiting Astronomers Section
European Southern Observatory
Karl Schwarzschild Straße 2
D–85748 Garching bei München
Germany

The ESOFORM package, containing all information required to generate electronic application forms using LaTeX macros, and instructions on how to submit observing time proposals via e-mail, is available to Internet users via *anonymous ftp* and to SPAN users via VAX/VMS *copy* through DECnet.

The e-mail submission facility will accept only text and tables but not figures and pictures. Please note also that e-mail submission of proposals will only be accepted if made using the ESOFORM style macros and submitted to *proposal@eso.org* or *ESO::PROPOSAL*, special mail-only accounts created only for this purpose. Proposals submitted after midnight (Central European Time) of the deadline will be automatically rejected by the facility.

Detailed instructions for retrieving ESOFORM over SPAN and INTERNET are provided in the Announcement for Observing Time (published semi-annually).

1.5.3 Notification of telescope time allocation

Proposals are considered by the OPC and telescope time is awarded on the basis of scientific merit.

The applicants receive notification of the decision about 3 months after the proposal submission deadline.

Note:

For reasons of organization of the introduction schedules at La Silla, it is compulsory for each successful applicant to indicate the name(s) of the observer(s) who will conduct the observations of the programme(s) at La Silla, as follows.

• For programmes scheduled between 1 April and 1 July, the name(s) of the observer(s) has to be indicated by 1 March, at the latest. • For programmes scheduled between 1 July and 1 October, the name(s) of the observer(s) has to be indicated by 1 June, at the latest. • For programmes scheduled between 1 October and 1 January, the name(s) of the observer(s) has to be indicated by 1 September, at the latest. • For programmes scheduled between 1 January and 1 April, the name(s) of the observer(s) has to be indicated by 1 December, at the latest.

We would like to draw your attention to the fact that the observer should be one of the applicants; a replacement can only be accepted under exceptional circumstances. Please note that a change of observer(s) at the last moment might mean that no introduction can be given at the telescope. Most telescopes are heavily oversubscribed and consequently competition for observing time is strong. For each period of 6 months, a brochure is distributed by ESO describing recent instrument changes, policy changes and giving telescope application statistics. Astronomers using the CAT or NTT telescopes may be required to use remote control from Garching.

1.6 Telescope operations and assistance

The staff of the Technical Research Support department (TRS) at La Silla prepare the telescope and equipment for each observational programme. In general, these preparations are done the morning before the observations begin. The equipment is tested on the telescope in the afternoon with the introducing astronomer and the VA should be present during these tests.

In addition, the TRS provides the different grating and filter set-ups required for the observations. In order to ensure a proper service, the VA is required to fill in a "request" form (available in the astronomy lounge) on the day he/she arrives at La Silla, and an additional form at the end of each night's observation for the following night. Requests may be sent in advance through electronic mail to `OPERATION` (DGAESO51 bitnet, eso.org internet). However, it is recommended that the set-up request is filled together with the introducing astronomer, as some configurations may change.

A pad of operations report forms is provided at each telescope. The VA can state therein all difficulties encountered during the night and make requests for necessary materials for the following night's observations. These operations reports enable the technical staff to do repair work during the day and to fulfill additional requirements, etc.

These reports should be completed every night even if you do not observe. *Please complete all entries on the form.* All request forms for gratings, etc., and the blue and pink copies of the operations reports should be deposited into the red letter box at the entrance to the hotel. The top (white) copy of the operations report should be left in the ring binder in the control room or dome. Set-up requests and operations reports should be deposited before 07.45 a.m. every day. If this is not possible, please page the operations group at 93–54. The operations group is responsible for the following "on-line" tasks:

1. First action in the morning. Analyze the telescope night reports and assign technical resources according to the observer's comments and requests.
2. Coordinate instrument and detector exchanges with the different technical groups.
3. Follow up all the interventions inside the telescope domes during daytime. Participate in the equipment fault diagnostics.
4. Prepare and evaluate the instruments' performance before observations start.

This is applicable to all telescopes and instruments with the following exceptions:

- Schmidt telescope.
- Infrared instrumentation and detectors. Here there is a special team (page numbers 93–43 or -28).

1.6.1 Staff astronomers

Each week one of the staff astronomers acts as team leader and another astronomer as astronomer on duty from Tuesday 15:00 hours to Tuesday 15:00 hours and his/her names and phone numbers are displayed on the astronomy lounge notice board.

The team leader can be approached for astronomical and general advice. If the VA is a first time observer to a particular instrument or telescope, a staff astronomer will be assigned to introduce the VA to the telescope and instrumentation and give hints and advice on how best to carry out the programme. These introductions generally take place in the afternoon before observations begin, and the staff astronomer will remain with the VA at least part of the first night to ensure smooth operation. *VAs are expected to have read all relevant documentation pertaining to the instrument and telescope* (to be found in the Library and the telescope control room or dome) *before the introduction.*

Frequent users of the same equipment may not always receive a formal introduction. However, for any questions or details a staff astronomer will be pleased to help and answer any questions. The names of these persons appear assigned between parenthesis in the telescope schedule displayed in front of the astronomy secretary office and astronomy lounge.

VAs are strongly advised to become familiar beforehand with IHAP or MIDAS. During 1993 all instruments equipped with CCDs will have MIDAS as the standard on-line image processing system. Manuals can be obtained from the Visiting Astronomers Section in Garching.

1.6.2 Night assistants

Night Assistants (NA) are normally assigned to the 3.6 m, NTT, 2.2 m, 1.5 m ESO and CAT telescopes. During vacations, however, the 2.2 m, the CAT and the 1.5 m may have to be operated with partial assistance only, but a NA is always available at the 3.6 m, NTT, and at the 2.2 m for IR mode.

NAs are familiar with the telescopes and equipment, but are *not responsible* for conducting the actual observing programme.

1.6.3 Special requests for assistance

An assistant can be made available for infrared observations during daytime at the 3.6 m telescope, if requested. This request should be made with your observing proposal and be confirmed with the VA section in Garching on receipt of allocation of observing time.

VAs should keep in mind that the scheduling of introductions and assistants is based on the information provided in the observing proposal, in particular on the observer's experience, and is made several months in advance. For this reason any last minute change of observer may result in support which is not at the optimum level.

1.6.4 End of mission Report

At the end of an observing run, VAs should fill an end of run report using a special form available from the Astronomy secretary or at the Astronomy lounge. These forms are extremely useful for assessing the quality of the services provided at La Silla and VAs are kindly requested to make comments about all aspects of their observing run that they may consider relevant, including the quality of the introduction, of the night assistance, the TRS support, etc.

1.7 Observing regulations

1.7.1 Closure of domes due to weather conditions

Wind speed

At the 3.6 m and CAT telescopes the astronomer should not observe into the wind for wind speeds over 90 km hr^{-1} and should close the dome when the wind speed is ≥ 100 km hr^{-1}.

For the other telescopes, a master anemometer monitor is located at the ESO 1 m telescope (ground floor). The wind speed is relayed to all domes, to the hotel (in the area by the mailboxes), and to a device in front of the astronomy dormitories 3 and 4. Each dome device shows two lights —red and orange— that indicate the wind speed as follows: orange: $V<14$ m s^{-1} allowing observing; orange + red: $14<V<20$ m s^{-1} no observing into the wind; red: $V>20$ m s^{-1} close dome.

Above 20 m sec^{-1}, the wind begins to carry a significant quantity of dust which is harmful to the optical components of the telescope and instrumentation. Furthermore, telescopes with a closed tube structure such as the 1.5 m ESO can be subjected to strong wind pressures, possibly resulting in damage to the drive system.

The lights on the indicators at dormitories 3 and 4 and the hotel show a green light (<14 m s^{-1}), orange light ($14 \leq V \leq 20$ m s^{-1}) and a red light (> 20 m s^{-1}).

The meteo information including wind speed, humidity, atmospheric pressure, and seeing is also available through the Ethernet giving the commands `INFODIMM` or `METEOMONITOR` on any workstation or X11 terminal.

Humidity

When the relative exterior humidity reaches 95%, the observer must close the dome. This is to avoid condensation on vital optical components and to avoid the breakdown of electrical insulation in high voltage equipment. The dome may be reopened when the relative exterior humidity has decreased 90%. Master humidity meters are located at the 3.6 m, NTT, and 1.5 m ESO.

Note:

> *When wind speeds or humidity approach the critical values indicated above, the VA should contact the astronomer on duty for advice regarding the feasibility of observing. The word of the duty astronomer regarding dome closure for either wind or humidity is final.*

Smoking and beverages

Although smoking is permitted in the domes, it is strongly discouraged. Food and beverages should be kept well away from computer terminals, keyboards and other such equipment.

1.7.2 Failures of equipment or telescope

Should the observer experience any instrument or telescope failure during the night, he/she should phone the appropriate engineer until up to three hours before sunrise. The key personnel on night-duty are equipped with pagers. A list of rooms, phone numbers and page codes of the mechanician and electronician on call for a given night is posted in each dome. If the failure occurs after 3 hours before sunrise you should include a full account of the problem in the night report. The problem will then be dealt with during the rest of the day. *Submitting a well documented report of a failure or problem is of great importance to the TRS group to be able to effect adequate repairs or replacements.*

1.7.3 Daytime observing

Infrared observations may be carried out during the day. At no time should direct sunlight fall on the telescope structure. IR observations are carried out at the 3.6 m, NTT, 2.2 m, and 1 m telescopes. In the case of the 1 m telescope, the astronomer should take care to move the dome manually and not use the automatic mode.

1.7.4 Darkroom practice

Fresh chemicals and plates are replaced on request using the forms provided. Darkrooms must be kept clean at all times.

1.7.5 Magnetic tape policy

Magnetic tapes are supplied by ESO, and are the property of ESO. A copy of your tape will be held at La Silla for a period of six months. Two copies of the night data tape are produced every day by the computer operator on duty: one copy for the La Silla databank at 6250 BPI recording density and with the IHAP output format; a second copy is made for the observer who can choose the recording density (800, 1600 or 6250 BPI) and the output format (IHAP or FITS). A special form found in the astronomy lounge should be used to specify these options. Copies on DAT cartridges are also provided.

Utilities to copy standard tapes onto Exabyte cassettes are available on La Silla, but observers wishing to use these facilities must make their own copies. No service is presently available.

1.7.6 Light pollution discipline

In order to maintain the high quality of the La Silla site, each VA is asked to cooperate by trying to avoid producing unnecessary light pollution. Switch off all unnecessary lights, keep curtains and window shutters closed at night, and keep trips by car to and from telescopes to the minimum necessary.

1.8 Remote observing from Garching

ESO routinely operates some of the La Silla instruments under remote control from Garching. At present, these are

- The EMMI and SUSI instruments at the NTT (see section 3.9 and 3.10).
- The 1.4 m Coudé Auxiliary Telescope (CAT, cf. Section 2.9) with:
  - The short camera (see Section 3.8).
  - The long camera (see Section 3.8).

Under remote control, the functionality of the instruments is the same as when they are used on La Silla. The user is therefore referred to the sections of this manual which are mentioned above. Furthermore, the observer interacts with the instrumentation via the standard form-filling system described in Chapter 5 in exactly the same way as if he/she were in Chile so that he/she hardly sees a difference. (In principle, this is no surprise because also at La Silla the observer commands the equipment remotely from the consoles in the control room.) IHAP is available for on-line data analysis for CAT observations and MIDAS for EMMI/SUSI observations.

Commands and data are transmitted over a telephone line which is permanently leased by ESO. Instrument control commands are, therefore, nearly instantaneously executed, but the current bandwidth of 64 kbit/s implies that the transmission of an image with 520 × 330 pixels requires about 1 minute. Since the speed is roughly proportional to the number of pixels, windowing (e.g. for spectroscopic applications) and binning of the CCD can lead to substantial savings. Data transmission can easily be done during any subsequent exposure.

For object identification, images from the field acquisition TV camera can be transmitted using the same line. The screen is refreshed every 25 sec. Thus, if a source needs to be accurately centered, it is more efficiently done by the night assistant at La Silla.

The night assistant will be permanently present to help with the focusing, pointing and guiding of the telescope, the preparation of flat field exposures, etc. In order to facilitate and speed up the object acquisition, the observer is expected to supply coordinate lists and high quality finding charts several days in advance.

In Garching the system operation is handled by a remote control operator. A support astronomer will usually stay with the observer during part of the first night in order to ensure that the observing programme gets properly started. Communication with the night assistant at La Silla normally is by means of typed messages, but in case of problems the line can be switched to voice mode.

Apart from the scientific and technical support which includes all other visitor facilities in Garching, for the duration of their observations RC observers are provided with a permanently available car, accommodated in a quiet room in a nearby guesthouse in Garching, and provided with a choice of food in a fully equipped self-service kitchenette.

ESO reserves the right, for organisation reasons, to prescribe or cancel remote control as the observing mode, after consultation with the principal investigator. Presently, as a rule, first time observers will carry out their observations at La Silla although this is in no way required by the remote control facility.

Together with the confirmation of their allocation of observing time RC observers will be sent an RC User Guide in which all essential information required for the preparation of the observations can be found.

1.9 Astronomical support facilities

1.9.1 La Silla library

The astronomical library is located on the upper floor of the Astronomy and Administration building. All major journals and principal text books, astronomical reference sources, catalogues and instrument manuals are kept there. A typewriter is also available in the library.

In the atlas room, sky surveys available are: ESO B and R, and SRC UK Schmidt J, I and SR on film, and the Palomar Sky Survey on paper. There is also a light table with a variable magnification binocular microscope for inspection of plates. Additionally, a facility to make Polaroid finding charts (see "Finding Charts" below) exists.

1.9.2 Finding charts

The VA should prepare finding charts in advance. However, there is a Polaroid camera and a small quantity of Polaroid film to copy film or prints. 1×, 2× and 3× enlargements can be made on standard 7.5 × 9.5 cm film.

The camera and films are kept in the atlas room. Please advise the astronomy secretary if the film supply is low and needs replenishing. Instructions for use are displayed at the light table.

A TV camera connected to a SUN workstation is available for digitizing photographs. The interactive astrometry package `STELLA` may be used to determine coordinates on the digitized images useful for pointing the telescopes. A user's guide for `STELLA` may be found in the atlas room.

1.9.3 Data reduction facilities

Besides the instrument control computers at the various telescopes, data reduction facilities are available at the computer centre located on the ground floor of the Astronomy and Administration building.

These facilities comprise an HP 1000/A900 computer with fully equipped IHAP image processing stations, a VAX 11/750 mainframe, and a number of SUN workstations for MIDAS image processing.

Reduction programmes are available for optical and infrared photometry (SNOPY), for Walraven photometry, and for PISCO polarimetry. Note, however, that while VAs are welcome to use any of the reductions facilities on La Silla if and when available, (limited) support can only be expected for photometric reductions.

Manuals are available for the major reduction packages.

References

- IHAP Users Manual
- MIDAS Users Manual
- SNOPY Manual
- Reduction programmes for Infrared photometry on La Silla
- The MIDAS Contexts `FILTERS`, `SPECTRA`, and `FOURIER`.
- `STELLA`: An interactive astrometry package.

1.9.4 The astronomy secretary

The office of the astronomy secretary is located in the Astronomy and Administration building near the library. The VA may obtain all normal supplies such as writing equipment, paper, graph paper, etc. A limited number of portable calculators are available for loan. The secretary can also assist with overseas telephone calls, wrapping of tapes or photographic plates for sending to the home institution, etc. He also manages the astronomy cars to which are entitled the observers at the 3.6 m, 3.5 m NTT, and CAT telescopes.

1.9.5 Astrophysical seminars

Seminars are usually held at La Silla on Thursdays. The purpose is to stimulate an informal scientific discussion between astronomers present on the mountain. VAs are encouraged to give a short talk about their ongoing research work. It is emphasized that the format of the tea is informal. Usually VAs are contacted well before their visit to La Silla about giving a talk.

1.9.6 Astronomy lounge

An astronomy lounge is available for use by staff and VAs. All preprints received during the current month, the latest issues of some important journals, instrument request forms and an information board are located in the lounge.

1.10 La Silla weather statistics

1.10.1 Photometric nights

The average percentage of spectroscopic and photometric nights (defined as nights with 6 or more consecutive hours of clear sky) for the last 5 years is plotted in Fig 1.1 as a function of month of the year. A strong seasonal dependence is clearly present and an estimate of expected conditions can be made from these data.

1.10.2 Seeing

Seeing data from a consistent seeing monitoring programme using CCD exposures taken at the 3.6 m, 2.2 m and 1.5 m Danish telescopes are shown in Fig. 1.2. The median value for the seeing at La Silla is about $0\overset{\prime\prime}{.}85$.

Seeing is also continuously monitored by a DIMM seeing monitor located near the Schmidt telescope. The seeing information is relayed to the La Silla Ethernet line and can be read using the programs INFODIMM or METEOMONITOR.

1.10.3 Temperature

The mean diurnal temperature variation at La Silla is shown in Fig. 1.3 as a function of time throughout the year.

1.10.4 Sky brightness

The sky brightness varies with weather conditions, zenith distance, season, and solar activity. It can also vary during the night! The following values are taken from Schnur, G.F.O and Mattila, K., 1979, Mitt. Astron. Ges. **45**, 196 and were determined in Feb. 1978.

Passband	Magnitudes arcsec^{-2}
U	22.00
B	22.96
V	21.90
R	21.17
I	20.18

1.10.5 Night length/sidereal time

An idea of the night length and sidereal time throughout the year for La Silla is given in Fig. 1.4. This table was provided by Prof. E.H. Geyer and should prove especially useful when making out observing proposals.

1.10.6 Extinction

Extensive extinction measurements have been made by Dr. H. Tüg of the Astronomical Institute of the Ruhr University in Bochum, using the 0.6 m Bochum telescope at La Silla and a photoelectric rapid spectrum scanner.

In Table 1.1, the wavelength and extinction coefficients in mag airmass^{-1} are given. Typical extinction coefficients for different photometric systems can be estimated from these tables.

No correlation was found between the extinction coefficients and the direction of observation. The measurements were made on photometric nights and were found not to differ from night to night by more than 2% at 500 nm. More detailed discussion of extinction on La Silla can be found in the ESO Messenger # 11, December 1977. Notice however that the extinction has changed significantly after the eruption of Mount Pinatubo in 1989. The extinction is still high at the time this edition was prepared (May 1993) and therefore observers are strongly advised to carefully monitor extinction during their observations.

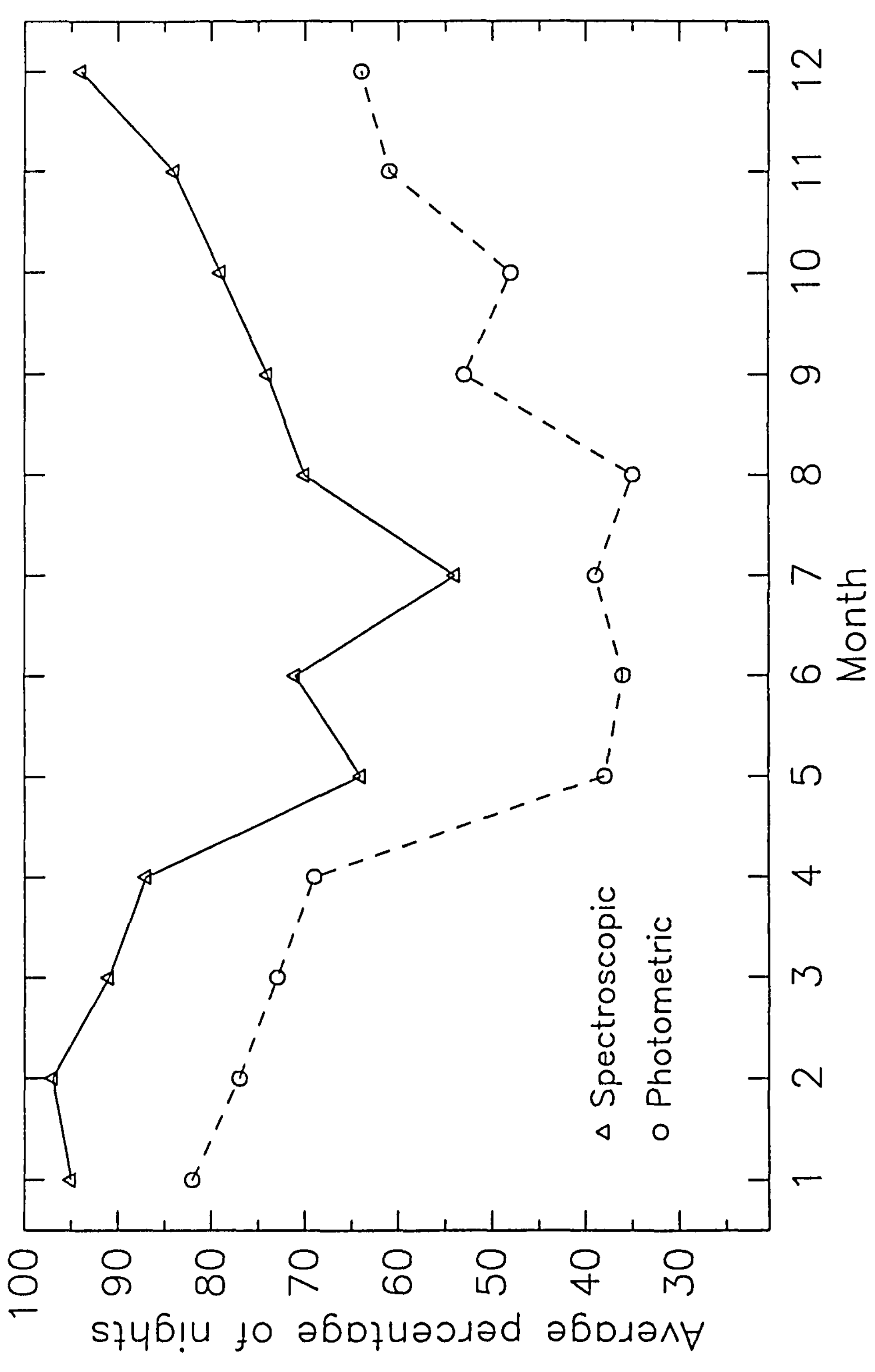


Figure 1.1: Photometric nights at La Silla

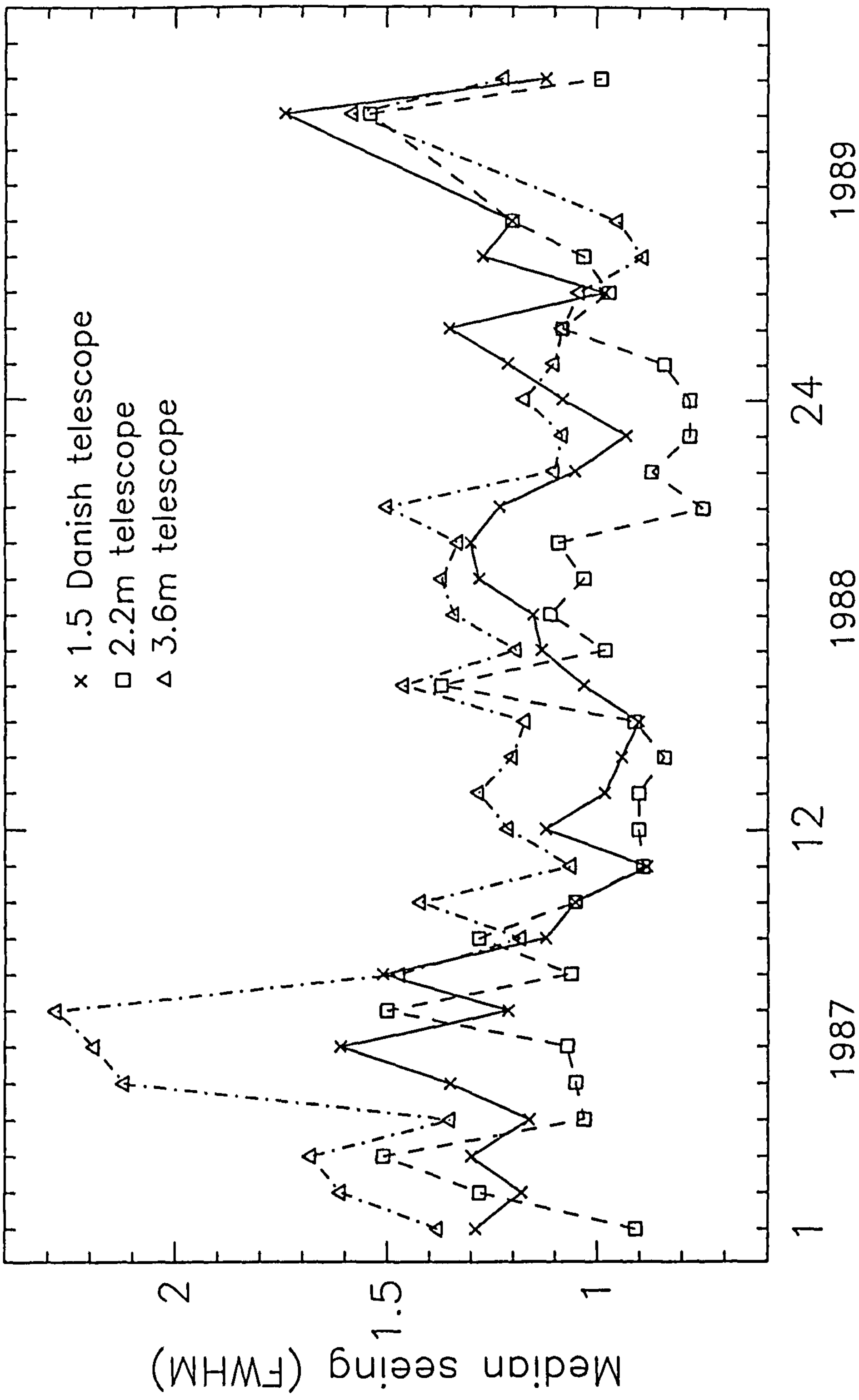


Figure 1.2: Seeing at La Silla

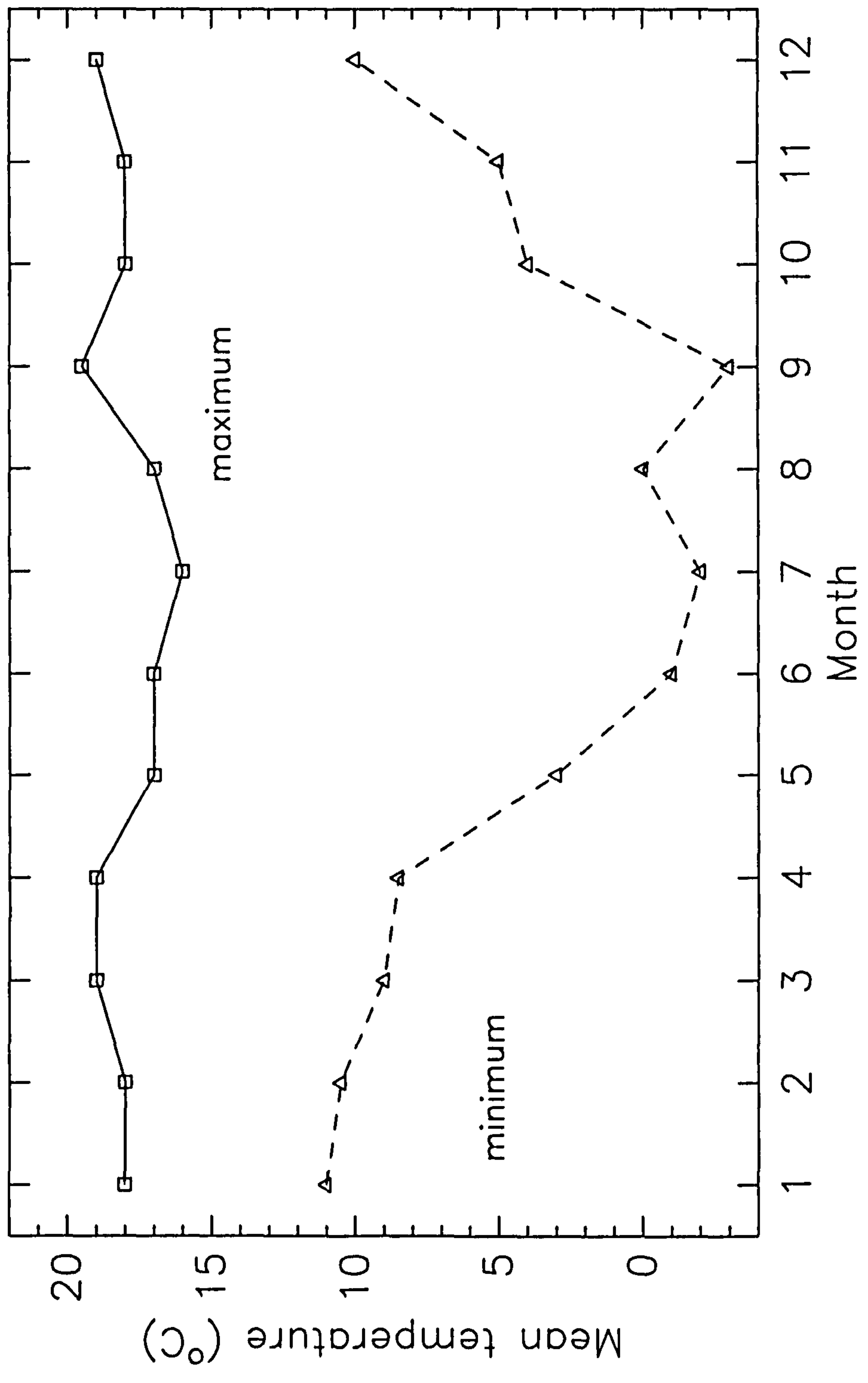


Figure 1.3: Temperature variation at La Silla

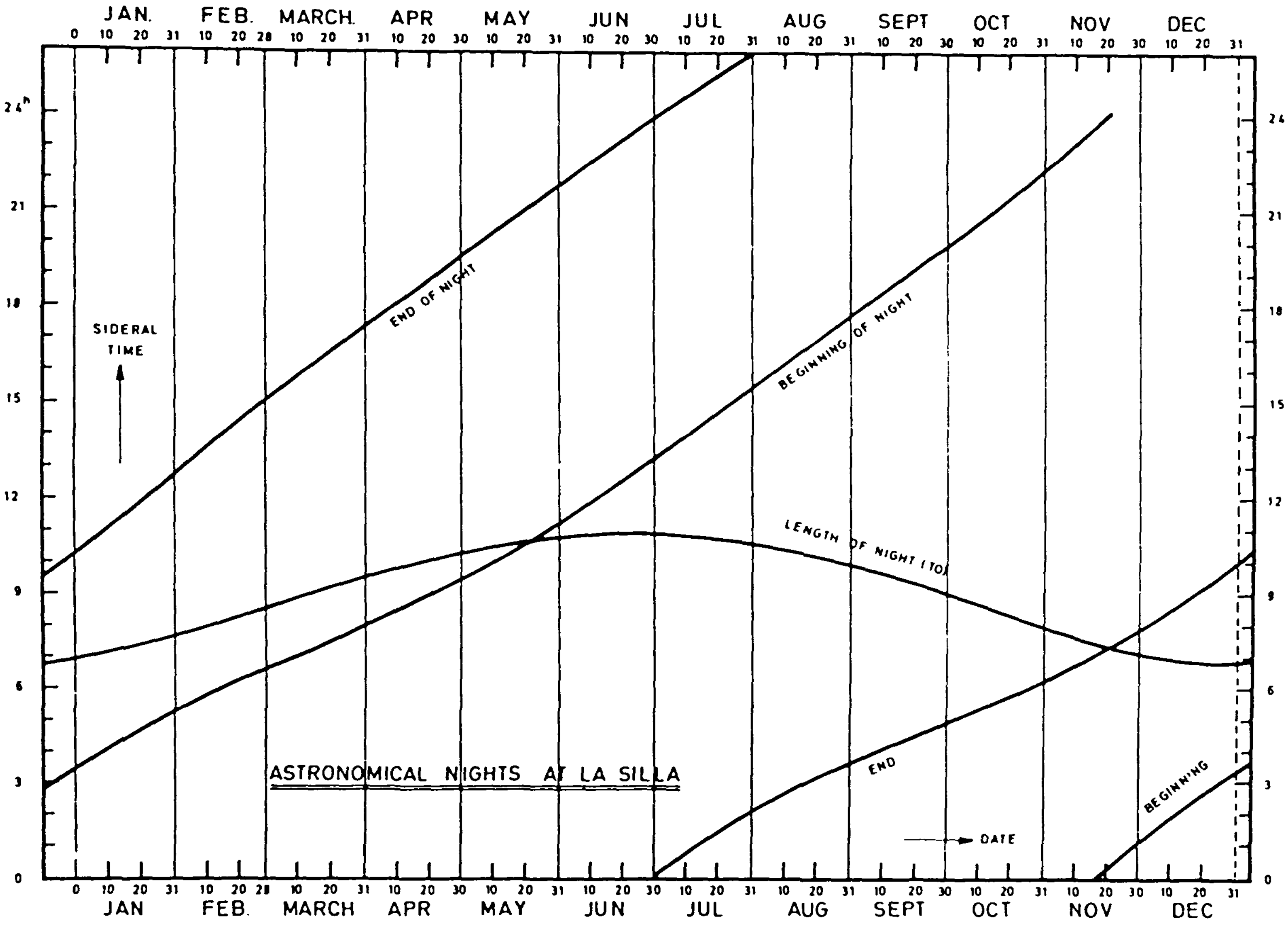


Figure 1.4: Length of night and sidereal time

Table 1.1: Extinction as a function of wavelength for La Silla

λ	mag airm^{-1}	λ	mag airm^{-1}
3100	1.53	5200	0.12
3200	0.94	5400	0.11
3300	0.72	5600	0.11
3400	0.60	5800	0.10
3500	0.52	6000	0.09
3600	0.46	6200	0.08
3700	0.41	6400	0.07
3800	0.37	6600	0.05
3900	0.33	6800	0.04
4000	0.30	7000	0.04
4100	0.27	7200	0.03
4200	0.25	7400	0.03
4300	0.22	7600	0.02
4400	0.20	7800	0.02
4500	0.19	8000	0.02
4600	0.17	8200	0.02
4700	0.16	8400	0.01
4800	0.16	8600	0.01
4900	0.14	8800	0.01
5000	0.13	9000	0.01

1.10.7 Airmass

An airmass diagram for La Silla is shown in Fig. 1.5.

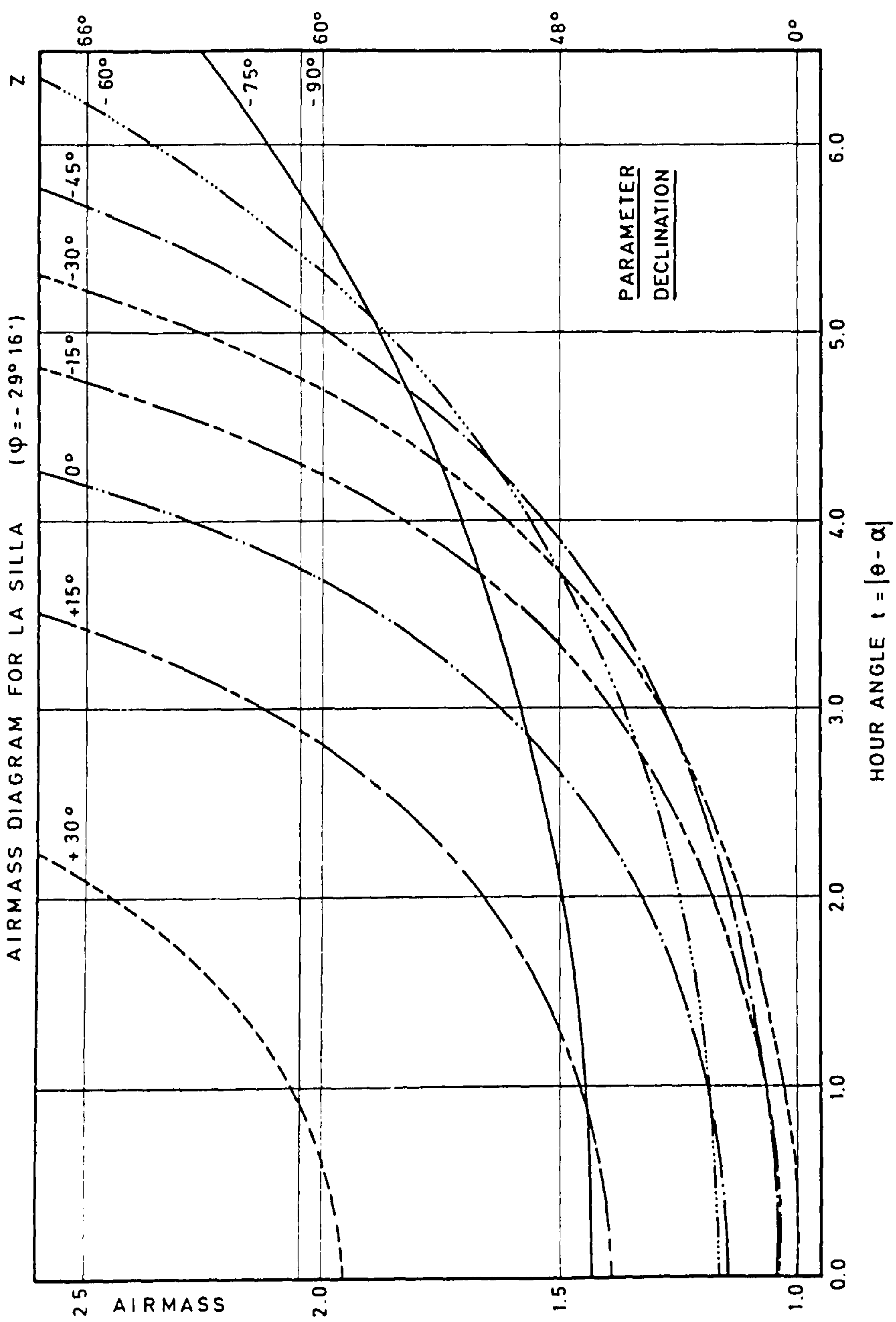
1.10.8 Airglow

Airglow lines are often seen on spectra of faint objects and particularly in the red region of the optical spectrum. A general description and identification of these lines can be found in Broadfoot, A.L. and Kendall, K.R., 1968, Journal of Geophysical Research and Space Physics **73**, 1, page 426. Airglow is much increased during periods of high solar activity.

1.11 General transport and shipping of equipment

1.11.1 Shipping instructions

The VA may wish to bring special equipment to La Silla. At least three months before shipping, the VA should contact the Visiting Astronomers section in Garching who will



AIRMASS DIAGRAM FOR LA SILLA I.K.1.FIG.5

Figure 1.5: Airmass diagram

provide the necessary details and instructions for shipment of the equipment.

Two copies of the pro-forma invoice should accompany the airway bill (AWB). The pro-forma invoice must contain a brief description of the material and its approximate value. The equipment should be addressed to:

European Southern Observatory
Casilla 19001, Santiago 19, CHILE
Attention: Import Department
Telephone: 56-2-2285006

The equipment has to arrive at least two weeks in advance, to allow time for customs clearance and other formalities. This will ensure that the equipment is on the mountain when the VA arrives.

Please inform the Garching office by telex about: flight number, AWB number, and the date of dispatch of the equipment.

1.11.2 Transport insurance

ESO covers transportation and insurance costs. Copies of the pro-forma invoice should be sent to the Garching office (marked "Attention: Purchase/Shipping Department") well before the shipment of the equipment to Chile.

1.11.3 Customs procedures

In order to obtain customs clearance of the equipment, ESO first has to request the *liberation of merchandise* from the Chilean ministry of foreign affairs.

This formality can only be carried out after the arrival of the equipment and receipt of the proper documentation (copy of the pro-forma invoice and AWB). Liberation and customs clearance take together 8 days approximately. Transport of the equipment from Santiago to La Silla normally takes place each Tuesday. Arrival at La Silla is on Wednesdays.

1.11.4 Round trip: home institute—Santiago—home institute

VAs will receive notification of allocated observing time together with proposed travel arrangements from the Secretariat of the Visiting Astronomers Section in Garching. Normally, the ESO office in Garching purchases the most economical return air ticket via the most direct route between the VA's home institute and Santiago.

Note:

> *Organization and expenses of any additional trips or ticket cost increases associated with stop overs on the way shall be the full responsibility of the Visiting Astronomer. Past experience has shown that VAs interrupting travel to Santiago are often delayed by unforeseen circumstances and travel by the most direct route is therefore strongly recommended. Within Europe, first class train travel or economy flights are approved.*

If more than one astronomer wishes to travel to Chile for the same programme, ESO may, in exceptional cases, contribute to the costs of the second person.

VAs are expected to arrive at La Silla two days prior to their run, and at least one day before this in Santiago to acclimatize and allow travel time to La Silla from Santiago.

Any delays of the scheduled flights due to unforeseen circumstances should be reported as soon as possible by telex/telegram: 240853 ESO/ESOSER, or phone +56 2 2285006.

After arrival in Santiago International Airport (Comodoro Arturo Merino Benítez, but commonly known as Pudahuel) the VA will be met by a taxi driver of *Airport Service* who will have instructions for his destination either the ESO guesthouse or a hotel. For the VA's return trip, taxi transport is usually via *Radio Taxis Andes-Pacífico* and is also provided by ESO.

1.11.5 Santiago—La Silla—Santiago

It is advisable to contact the guesthouse supervisor or to call the Santiago office so that visa formalities and other matters may be discussed. The VA will then also be informed of the details of travel to and from La Silla. Standard modes of transport to La Silla are:

1. Charter plane transport.
    (a) The plane is a twin engine, seating 8 passengers and is chartered by ESO for transport to and from La Silla. In general, luggage is easily accommodated on the plane, but it is possible that no space is available for large suitcases. The VA is therefore urged to pack only essentials in an easily transported handbag. Further luggage may be sent by road transport or via the plane with one of the next flights. Flights to and from La Silla are made Mondays, Tuesdays and Fridays, normally leaving from Los Cerrillos airport in Santiago. The actual flight duration depends on weather conditions, but is approximately 1 hour 45 minutes. The total time for the trip including road transport time to and from the airports is approximately 3 $\frac{1}{2}$ hours.
    (b) Commercial flights are available on days without scheduled ESO charter flights. These planes leave from and arrive at Pudahuel airport in Santiago. Transport to and from the airport in La Serena and La Silla is organized by ESO. The total travel time is about 5 hours.

2. Road transport.
    (a) By ESO car – Rarely used. The car trip from Santiago to La Silla takes about 8 hours.
    (b) By public bus – The VA may be requested to travel by public bus between Santiago and La Serena or between Santiago and a bus stop (La Frontera) near La Silla; the travel time is at least 7 and 9 hours respectively. Under these circumstances, ESO will provide car transport to and from the respective bus stops. From "La Frontera" (a popular roadside inn) to the mountain top, a car takes a further 40 minutes.

Note:

"La Frontera" has some limited radio contact with La Silla in the event of unexpected delays, etc.

1.11.6 Luggage note

VAs are advised to carry all materials indispensable for the observing run (i.e. finding charts, object lists, etc) in their hand luggage. In the event that your main baggage is delayed you will still be able to conduct your observing programme.

The climate in central Chile is best described as Mediterranean, but do not forget that the seasons are reversed. Typical temperatures are 28°C in summer (January) and 15°C in winter (July). The temperatures on La Silla are similar during the day, but occasionally can drop below zero during winter nights. You should therefore dress accordingly. In general, casual sports clothes (e.g. blue jeans, casual shirts and woollen sweaters) and sturdy, comfortable walking shoes are ideal observatory wear. Observing jackets and trousers are provided by the Observatory. For observations during winter time, warm socks or stockings are recommended.

1.12 ESO in Germany – Garching bei München

The ESO building is located adjacent to the institutes of the Max Planck-Gesellschaft, about 2 km NE of Garching and 15 km NE of central Munich. The Visiting Astronomers Section will send to all people travelling to Garching the necessary maps and information.

To get there:

1. Arrival by air. At the Munich airport try to get hold of a taxi. Show the driver the address. The ride will take about 20–30 minutes and costs about DM 50–70. A cheaper alternative is to use the train ('S-Bahn', see also next section) towards Munich and get off in Ismaning. The train fare is DM 7.50, and the taxi (there are virtually no buses) from Ismaning to Garching will cost another 20–25 DM. However, if you arrive in Ismaning at off hours, you may not find a taxi waiting at the station.

2. **Arrival by rail.** Take the S-Bahn from the main railway station to Marienplatz and then the U-Bahn U6 in the direction Kieferngarten as far as the station "Studentenstadt". From there you can get to ESO on bus 290 which goes right to ESO at the "Forschungsinstitut" stop.

3. **Arrival by road.** There is a system of autobahns in and around Munich. Follow these to the autobahn for Nürnberg. After only a few kilometres on this autobahn you will see the turn off for Garching Nord. Follow that road until you reach the Forschungsinstitut area.

On arrival at ESO building go to the reception by the main door, from where you will be directed to the Visiting Astronomers Section where all other arrangements for your visit will be made. An ESO astronomer will be available to introduce you to the data reduction facilities.

If you intend to arrive after 17:00 hours or on a weekend, notification should be given in advance. The guard at the main entrance will then show you the guest rooms.

Four single rooms are available for VAs in the ESO building. The rooms are equipped with shared kitchen, dining room, and bathroom/toilet facilities. Towels, linen, soap, etc., are provided, and the rooms are serviced daily.

For visiting astronomers staying in the ESO guest rooms, meals may be purchased at the MPI canteen on the Forschungsinstitute campus Monday to Friday. The ESO kitchen is equipped with the usual utensils and food can be purchased at several nearby stores in Garching.

Besides bus and taxis, ESO cars may be used on weekends with prior permission for travel within the Garching/Ismaning area. Also two ESO bicycles are available.

The Visiting Astronomer is encouraged to feel part of ESO's scientific group and to take part in the regular colloquia which are usually held Tuesday lunch (12:30–13:30 informal) and Thursday 11:00 a.m. These meetings provide an opportunity for you to hear what is going on at ESO, and for us to hear about your home institute and your own scientific work. There is also the possibility to attend colloquia at the Max-Planck-Institut für Astrophysik in the next building. These are normally posted on the bulletin board near room number 406 on the 4th floor.

More detailed information about the facilities for visiting astronomers in Garching can be found in the leaflet: "A Short Guide to ESO-Garching for Visiting Astronomers", which may be obtained from the Visiting Astronomers Section in Garching.

1.12.1 Telex and Fax

05 282 820 eo d. The secretary at the reception near the main entrance door will receive and send telex messages.

1.12.2 Telephone

0049 89 320 060 or 0049 89 320 06-*ext* where *ext* is the extension number you wish to call directly. When the satellite link is free, in order to reach directly Garching from La Silla dial 81-*ext*, and 76-*ext* in order to reach directly La Silla from Garching.

1.12.3 Mail

Any mail sent to you in Garching should be addressed care of the Visiting Astronomers Section, ESO, Karl Schwarzschild-Straße 2, D–85748 Garching bei München, Germany.

As everywhere else, the new postal code of Garching is no more 8046 but 85748.

1.12.4 Reimbursement of expenses

All reimbursements are handled by the secretary of the Visiting Astronomers Section, and evidence of expenses should be submitted on the appropriate form before leaving.

1.13 Data reduction in Garching

ESO provides facilities at Garching for the reduction of data obtained at La Silla.

The MIDAS image processing system is available for data reduction on the UNIX workstations connected to the central computer facilities. This system provides reduction packages for most of the major ESO instruments. The IHAP system is also available on an HP1000/900A computer.

Photographic plates can be analyzed using one of the two plate measuring machines. They can be used for measurements of accurate positions and digitization.

Visitors who come to Garching to reduce data obtained at La Silla may have their travel and part of their subsistence paid by ESO; this support is normally limited to the return travel and subsistence at DM 50 per day for a stay of typically one week, for the observer who obtained the data, once per observing trip. In addition, ESO will pay the cost of lodging.

After your observations, when you wish to make reservations for the use of Garching facilities, you should call or write to the Visiting Astronomers Section, specifying (1) name and address of the person who will come to Garching (this should normally be the person who actually made the observations), (2) nature of the reductions, (3) facilities requested and time required, (4) preferred dates, (5) mode of travel, and (6) any special arrangements for accommodation (visitors normally stay at the guest rooms in the ESO building).

You will then receive confirmation of your reservations, information on how to get to ESO/Garching, and manual(s) for the data reduction facilities which have been reserved for you.

The measuring machines can be reserved up to 60 hours per week between 08:00 and 24:00 hours, with a maximum of 20 hours per week in the period 08:00 to 17:00 hours on weekdays. The period between 00:00 and 08:00 hours does not come under these restrictions. The interactive computer reduction system is scheduled in a similar way except that only 4 contiguous hours per day can be scheduled in the period 08:00 to 24:00 hours with a maximum of 24 hours per week. These are the general guidelines, but there is some flexibility if justified.

All correspondence regarding the use of these data reduction facilities should be addressed to the Visiting Astronomers Section in Garching.

1.13.1 MIDAS

Hardware

The central computer facilities consist of a distributed system of UNIX workstations and servers interconnected through a LAN. Workstations and X-terminals use the OSF/Motif user interface. A number of peripheral units is connected to the system including B/W and colour postscript printers, pen plotters, scanners, and film recorders for both 70 mm B/W negative film and 35 mm colour slides. Besides the main facilities, two μVAX 3100 systems are available to provide VAX/VMS compatibility and network connection to SPAN.

MIDAS can be executed on any of the available workstations or servers. A number of UNIX workstations are located in the main user room. The X11 display systems are used for both terminal input, graphics, and image display.

The tape units available for data exchange include 1/2″ 9-track tapes with 800 bpi, 1600 bpi and 6250 bpi, and a number of cartridge formats namely QIC–24/150, DDS/DAT, and Exabyte–8200/8500. Small amounts of data can be transferred through electronic network connections. It is recommended to use the FITS data format for data exchange.

Software

The MIDAS system was conceived in 1980 and first implemented on VAX/VMS machines in the following years. With the arrival of UNIX workstations in the mid-80's, MIDAS was made portable and is now available for both UNIX and VAX/VMS systems. Much of the basic philosophy was taken over from the IHAP system. MIDAS can be used interactively or in batch mode. The user can make procedures of individual commands and thereby create customized reduction sequences. It is also possible to write application programs in FORTRAN–77 and C.

The MIDAS system is available, free of charge, to all non-profit research institutes. Institutes interested in obtaining the MIDAS distribution must sign a User Agreement before distribution material can be shipped. The necessary forms can be obtained by contacting the Image Processing Group in ESO/Garching or the MIDAS Hot-line.

Documentation

The following documentation is available and is updated periodically:

- MIDAS User Guide Vol. A and B,
- MIDAS Environment Document,
- AGL Reference Manual.

General information on MIDAS and documentation can be obtained through the MIDAS Hot-line (Internet: `midas@eso.org`).

1.13.2 IHAP

IHAP (Image Handling And Processing), designed by F. Middleburg, is implemented on three workstations at Garching. Each workstation consists of a terminal, a plotter, a graphics terminal and a Ramtek with colour monitor. In addition there is a hardcopy device for the colour monitor.

IHAP can handle data from a variety of instruments. However, the system accepts only IHAP and FITS format magnetic tapes. There are a few routines to convert from foreign formats such as IUE, but these are limited and users are strongly discouraged from bringing foreign format tapes.

There are a number of specialized reduction packages for some special instruments. There is a package to reduce ESO IDS data which includes most if not all the functions needed to reduce data in a standard way. There are also packages for IPCS data and for IUE data. Some additions have greatly enhanced the capability to do stellar and surface photometry on image data. These routines are described in detail in the IHAP manual which is available on request to potential users.

IHAP is used interactively or in batch mode. At La Silla, IHAP is part of the standard data acquisition software.

Documentation

- IHAP Manual, 1989

ESO measuring machine facility

The plate measuring facility is located in the basement of the ESO headquarters in Garching and consists of two microdensitometers, namely: an Optronics S–3000 and a Perkin-Elmer PDS 1010A. Each of the machines is controlled by a VME-based system using the VxWorks real-time kernel. Data are dumped through a LAN to the central MMF UNIX server where they are stored on disk in either FITS or MIDAS format. The data can be checked directly on the MMF server using MIDAS. Users can then copy their data files to tape (i.e. DDS/DAT or Exabyte–8500) or to their own disk area with the `ftp` utility.

Optronics The Optronics S–3000 is a flat bed microdensitometer with a granite base and a stage moving on air bearings. It is mainly used for astrometric measurements. The positional accuracy is about 1μm. The stage can be moved over an area of 35 cm×35 cm and has a number of adaptors for different plate sizes up to 36 cm×36 cm (i.e. Palomar Schmidt plates). The machine has a Full Field CCD camera which covers an area of 3 mm×2 mm on the plate. Images from this camera are digitized and can be dumped to the central MMF server. A general scanning option is being implemented but is not yet available.

PDS The PDS 1010A microdensitometer has a low inertia stage capable of moving with a speed of up to 50 mm/sec^{-1}. It is possible to move the stage over an area of approximately 23 cm×23 cm, but larger plates can be mounted. Square apertures from 5 μm to 50 μm are available in addition to a number of slits. The effective dynamic range of the analogue system depends on the scanning speed used. At low speed values between 4 and 5 density units can be measured. The mean positional error is of the order of 2 μm for both axes. The PDS is recommended for measuring plates with a high dynamic range. Also programmes which require a large number of stage motions should be executed on the PDS.

The sky atlas laboratory – blink comparator The Zeiss Blink Comparator is available in the Plate Storage Vault (Room # 18). It permits blinking of 30×30 cm^2 plates. Also 14×14 inch^2 plates can be mounted, but only the central area blinked. Normal binocular or stereo microscopes are available (10× and 16×).

Sky atlases The ESO/SRC (on film and glass) and Palomar atlases (on paper and glass) are available at ESO/Garching. The Photographic Laboratory undertakes all kinds of photographic reproduction work for staff and, when justified, also for visitors. Note, however, that only limited capacity exists and that the usual delivery time is 1–2 weeks, although priority may be given to urgent cases. The Laboratory does not produce finding charts; these must be made by the astronomers at the Polaroid facility in the Plate Storage Vault (Room # 18).

1.13.3 European coordinating facility for the space telescope. ST/ECF

The Space Telescope–European Coordinating Facility (ST–ECF) was established in 1984 by agreement between the European Space Agency (ESA) and the European Southern Observatory (ESO) with the main goal of providing the European focal point of Space Telescope related activities. The staff is provided by both ESO (7) and ESA (7) with the latter being affiliated to the Astrophysics Division of ESA's Space Science Department; they reside in the ESO building in Garching and form a separate division within the ESO structure.

The role of the ST–ECF is to ensure that European astronomers are able to compete effectively in the exploitation of the telescope in which they have a 15% share. To achieve this, the three main areas of activity are:

- The provision of information about the HST, its Scientific Instruments and its mode of operation.
- The coordination of HST–related software development in Europe and with the Space Telescope Science Institute (STScI) in Baltimore.
- The establishment of the Archive which will contain a copy of all the observations made with HST.

Chapter 2

Telescopes

2.1 Introduction and overview

At present, 13 telescopes are operated by ESO, and one by the Observatoire de Genève, at La Silla. Table 2.1 presents a summary of the main properties of the various telescopes operated by ESO.

Table 2.2 lists the various instruments and detectors which can be used with the telescopes. At present 28 different telescope/instrument combinations are offered at La Silla.

2.1.1 Auxiliary equipment

Telescope control systems

The main telescopes at La Silla are operated using the standard ESO Telescope Control System (TCS).

The TCS runs on an HP computer and instructions to move the telescope to a given position, to change parameters, or to enter data are given via a menu driven program. Softkeys are used to perform most functions.

Object coordinates are entered into a catalogue which can be saved on cassette or disk for later use.

Coordinates can be given in epoch 1855.0 – 2000.0 and are automatically precessed. Setting and guiding speeds and offset step sizes can be set for RA and Dec independently as can the tracking rates, e.g. for cometary work. In most telescopes with the standard TCS, the instrument control program obtains the necessary data directly from the TCS – sidereal time and coordinates are stored in the data file header and can later be used for airmass calculation, etc.

Table 2.1: *Overview of La Silla telescopes*

Diameter (*cm*), name Optical design, f/ratios	*Mount* Manufacturer On La Silla since	*Longitude* Latitude Altitude	Remarks
357 (3.6m) Ritchey-Chretien Corning, USA f/8.1 Cass. f/3 prime f/32 Coudé, f/35 IR	horseshoe and fork Reosc, polishing and figuring Creusot-Loire, F. 1977	70°43'46"606W 29°15'25"814S 2400m	Sister of CFHT. M1 fused silica. Coudé focus not implemented.
358 (NTT) Zeiss/Schott, Germany Ritchey-Chretien f/11 Nasmyth	altitude-azimuth INNSE, Italy 1989	70°43'54"272W 29°15'18"440S 2375m	Thin mirror with active optics Zerodur New Technology Telescope (NTT)
230 (2.2m) Ritchey-Chretien f/8 Cassegrain f/35 IR	fork Zeiss, Germany 1984	70°44'4"543W 29°15'15"433S 2335m	Clear aperture 220cm.
154 (1.54m Danish) Ritchey-Chretien f/8.5 Cassegrain	English mount off-axis Grubb-Parsons, U.K. 1979	70°44'7"662W 29°15'14"235S 2340m	
152 (1.52m) f/14.9 Cass. f/31.4 Coudé	English cradle Reosc, France SOVIREL, France 1968	70°44'12"865W 29°15'7"422S 2335m	
140 (CAT) Dahl-Kirkham f/32.3 Nasmyth	altitude – altitude MAN, Germany Grubb-Parsons, U.K. 1980	70°43'53"9W 29°15'38"8S 2387m	Coudé Auxiliary Telescope (CAT) used to feed the 3.6m Coudé spectrograph. Moving third mirror.
104 (1m) Dahl-Kirkham f/13.6 Cassegrain	fork Rademakers, Netherlands 1986	70°44'10"870W 29°15'10"373S 2338m	
162 (Schmidt) Schmidt f/3	fork Heidenreich-Harbeck, Germany Schott/Zeiss, Germany 1972	70°44'1"403W 29°15'15"452S 2348m	Schmidt camera with clear aperture of 100cm. Objective prism of 100cm. Plates for Southern sky survey.
91 (91cm Dutch) Dahl-Kirkham f/13.8 Cassegrain	fork Rademakers, Netherlands 1979	70°44'14"518W 29°15'5"841S 2312m	Prototype for 1m telescope. From 1958 to 1978 in Hartabeespoortdam, South Africa.
1500 (SEST) f/0.325 Cassegrain	altitude – azimuth Neyrtec, France MAN, Germany 1987	70°43'48"0W 29°15'36"0S 2345m	Sub-mm telescope. Swedish-ESO Sub-mm Telescope (SEST) Subcontracted by IRAM.
50 (ESO) f/13.6 Cassegrain	fork Perkin Elmer, U.S.A. 1971	70°44'14"368W 29°15'4"359S 2325m	
50 (Danish) Dahl-Kirkham	fork Perkin Elmer, U.S.A. 1969	70°44'15"224W 29°15'4"077S 2325m	

Table 2.2: Available telescopes and auxiliary equipment

Telescope	Instrument
SEST	1.3 mm bolometer 1.3 mm receiver 3.0 mm receiver
3.6 m	TIMMI Come-On+ Fast photometer Cass. B & C spectrograph with OPTOPUS or MEFOS CASPEC EFOSC 1 Fibre link to CES IR photometer
3.5 m NTT	EMMI SUSI IRSPEC
2.2 m	Direct imaging adapter EFOSC 2 IRAC 2 IR photometer
1.5 m Danish	DFOSC
1.5 m ESO	Cass. B & C spectrograph
1.4 m CAT	CES with short or long camera
1 m	Infrared photometer Single channel photometer
1 m Schmidt	With prism Without prism
0.9 m Dutch	Direct imaging adapter
0.5 m ESO	Single channel photometer
0.5 m Danish	uvby Hβ photometer

At present the 3.6 m, 2.2 m, 1.4 m CAT, 1 m, 1 m Schmidt, and 0.9 m Dutch have a similar TCS. All other telescopes except GPO have different kinds of computer control systems.

Instrument flanges

Drawings of the instrument flange interfaces can be obtained from the TRS department on La Silla.

2.1.2 Adapters, TV systems, and guiding

The Cassegrain adapters at the 3.6 m, 2.2 m, 1.5 m Danish and 1.5 m ESO have offset guiding via intensified or CCD TV cameras. Typically, the object is acquired in a large field ($\sim 4' \times 6'$) and centered. Guiding is done by an offset guide probe which views the field near the object. At the 3.6 m, NTT, 2.2 m, 1.4 m CAT, and 91 cm Dutch there is an ESO autoguider. The autoguider works by centering a software "box" with cross-hairs on a suitable star and, after switching on, keeping the photon counts in 4 quadrants of the box equal. This is done automatically by giving the telescope small ($\sim 0''.1$) offsets to compensate for any imbalance. The 1.4 m CAT autoguider uses the starlight reflected off the slit jaws. Offset guiding here is impossible due to the field rotation.

The adapter at the 3.6 m telescope has different fields of view to allow easy acquisition of objects, as has the CES at the 1.4 m CAT.

The adapters allow instruments to be rotated — this allows for instance a spectrograph slit to be aligned with the parallactic angle (atmospheric refraction) or across extended objects. At the 3.6 m the parallactic angle is displayed on the TCS console. Note that at the 91 cm Dutch the adapter cannot be rotated.

Rotation is possible manually at the 2.2 m, and is remotely controlled to $0^\circ.1$ accuracy at the 3.6 m telescope adapter, at the NTT, and at the 1.5 m ESO telescope.

2.1.3 Computers and on-line data reduction

All major telescopes have HP computers for telescope and instrument control, and for data acquisition and storage. There are separate terminals for the TCS, instrument control and data handling, and graphics display. During exposures the IHAP system is available to reduce the previously obtained data. At the 3.6 m, 3.5 m NTT, 2.2 m, 1.5 m Danish, 1.5 m ESO, 1.4 m CAT, and 91 cm Dutch telescopes, a complete IHAP station with terminal, graphics terminal, Ramtek with colour/B&W monitor, and plotter is available. A hardcopy (colour or B/W) device is available to make copies of the Ramtek monitor pictures. In principle therefore, observers can reduce their data at the telescope and take plots home.

MIDAS is available at the NTT, 2.2m, 1.5 m Danish and 1.5 m ESO telescopes, and will become available at all telescopes equipped with CCDs in the course of 1993.

2.2 SEST — The Swedish–ESO Submillimetre Telescope

2.2.1 Introduction

The Swedish–ESO Submillimetre Telescope, acronym SEST, is a 15 m diameter radio telescope, which operates in the wavelength range 3 to 0.8 mm (frequency range 80 - 365 GHz).

The telescope, as its name implies, has been built on behalf of the Swedish Natural Science Research Council (NFR) and the European Southern Observatory (ESO), and is designed by IRAM. It is presently the only large millimetre/submillimetre telescope in the southern hemisphere.

On the Swedish side SEST is operated by the Swedish National Facility for Radio Astronomy, Onsala Space Observatory at Chalmers University of Technology, which is responsible for the receivers and the computer software. ESO is responsible for the mechanical and computer hardware maintenance as well as maintenance of the control building.

The observing time is split equally between Sweden and ESO on a month by month basis.

2.2.2 The telescope

SEST is a Cassegrain antenna with a rather low (3.5%) surface blockage.The reflector surface has been set with an overall rms deviation from the ideal paraboloid of about 70 μm. Future holographic measurements and subsequent adjustments of the surface are expected to reduce this rms deviation to around 50 microns.

The telescope stands in the open air and does not have a radome or other protective enclosure. The structure is strong enough to permit observations in winds up to 14 ms^{-1} (the survival wind speed is 56 ms^{-1}) and its thermal properties are such that temperature gradients due to differential solar heating across the structure do not affect the pointing.

Because of the danger of severe overheating of the subreflector region by reflected sunlight from the highly reflecting telescope surface, SEST is constrained never to track within 50° of the sun.

A full description of the telescope and original observing sytems has been published by Booth et al, Astron. Astrophys., 1989, **216**, 315, and an update was given by Nyman and Booth at the 29th Liége Colloquium, ESA SP-314 (December, 1990).

The main parameters of the telescope are given in Table 1.

2.2.3 Receivers

Heterodyne receivers

SEST is equipped with a dual polarization Schottky receiver covering the 3 mm atmospheric window, and two single polarization SIS receivers covering the 1.3 and 0.8 mm windows. The Schottky mixers are cooled to 15 K by a closed cycle helium refrigerator and the SIS mixers are cooled to 4 K by liquid Helium. The instantaneous IF bandwidth for all receivers is 1 GHz, and one of the 3mm Schottky receivers can be used simultaneously with the 1.3 mm SIS receiver. The Schottky mixers are tuned to SSB (Single Side Band) with a backshort and the SIS receivers with a SSB diplexer. The side band suppression is about 20 dB.

Table 2.3: SEST Parameters (From October, 1990)

Position:		
longitude	70°43'48" (W)	
latitude	-29°15'36"	
Diameter	15 m	
Surface accuracy	70 μm (rms)	
Half power beamwidth (FWHM):		
86 GHz	57"	
115 GHz	45"	
230 GHz	23"	
346 GHz	15"	
Main beam efficiency:		
86 GHz	0.75	
115 GHz	0.70	
230 GHz	0.60	
346 GHz	0.25	
Aperture efficiency:		
86 GHz	0.62	(25 Jy/K)
115 GHz	0.58	(27 Jy/K)
230 GHz	0.38	(41 Jy/K)
346 GHz	0.16	(98 Jy/K)
Moon efficiency:		
100 GHz	0.90	
230 GHz	0.90	
Pointing accuracy	3" rms in Az and El	
Max operational wind	14 m/s	
Sun constraint	50°	

During 1994 the 3 mm Schottky receivers will be replaced by SIS receivers covering the 3 and 2 mm atmospheric windows.

The receivers are tuned under computer control from the control room. With some experience the observer is able to tune without staff assistance whenever he or she wants to. A change of frequency normally takes 5 to 10 minutes.

Quasi-optics Fig. 2.1. illustrates the optical arrangement at the secondary focus. A chopper wheel switches between two beams symmetrically displaced in azimuth to each side of the telescope axis, the beam separation being 11'37" on the sky. For narrower beam separation, 2'27", the flip mirror in front of the chopper wheel can be flipped through 90° so that both beams are offset to the same side of the telescope axis, which should allow optimum cancellation of atmospheric fluctuations when observing unresolved sources. With the selection mirror one can decide which receiver to use.

The chopper wheel speed is phase locked to give a beam switching speed of 6 Hz. The

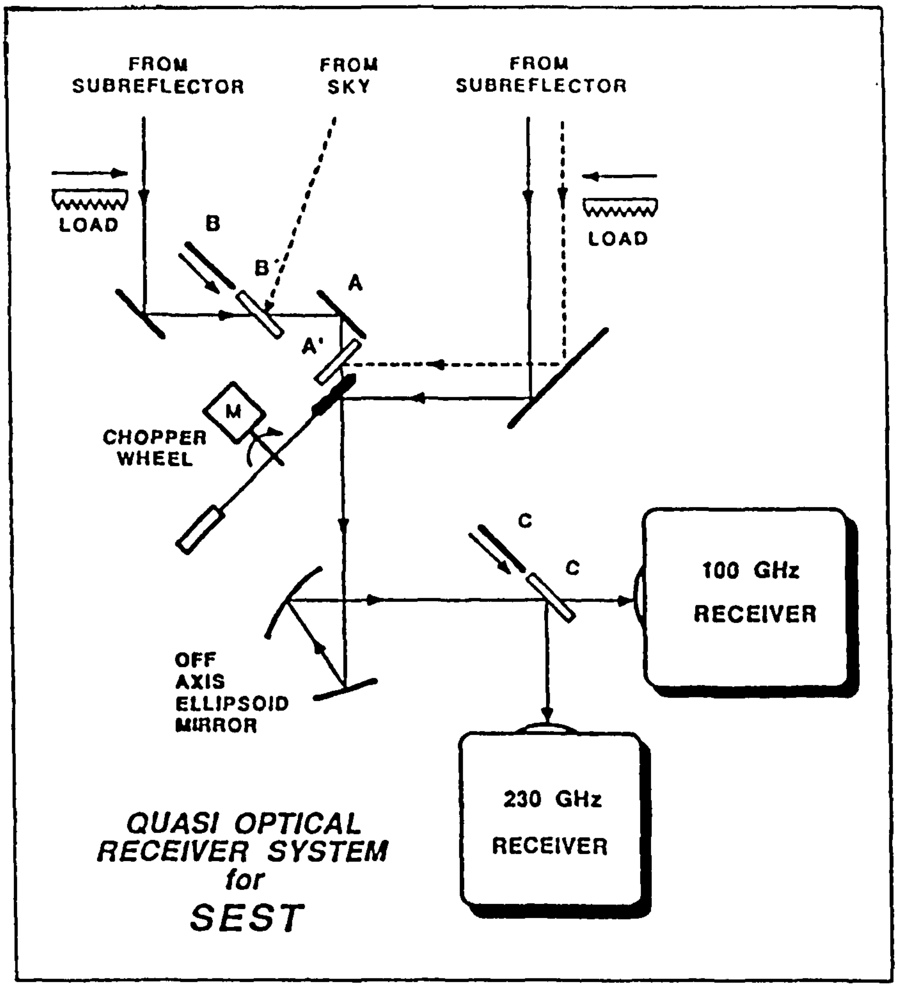


Figure 2.1: Quasi-optical arrangement at the SEST secondary focus

total blanking time per cycle is less than 10%. The chopper can also be stopped and used to switch between the signal and reference beams on command.

For calibration purposes, the reference and signal beams can be focused onto two temperature controlled loads, the hot load (approximately 322 K), and the cold load (approximately 275 K). A harmonic mixer is used to inject a synthesized test signal into the signal beam through the right load mirror, thus being common for both receivers. This test signal can be set for both sidebands and is useful for verifying that the receiver is tuned to the correct frequency and single sideband (SSB) operation.

3 mm receiver The 3 mm Schottky receiver can be tuned between 80 and 116 GHz. The receiver temperature varies between 200 and 325 K (SSB) as function of frequency. The two dual polarization mixers have similar receiver temperatures between 100 and 110 GHz, while one of them is better at frequencies higher than 110 GHz and the other at frequencies below 100 GHz.

1.3 mm receiver The 1.3 mm SIS receiver is on indefinite loan from the Center for Astrophysics, Cambridge MA. It can be tuned between 215 and 270 GHz. The receiver temperature varies between 400 and 1200 K (SSB) as function of frequency.

0.8 mm receiver The 0.8 mm SIS receiver can be tuned between 320 and 360 GHz. The receiver temperature varies between 300 and 450 K (SSB) as function of frequency. It is described in Whyborn et al. (ESO Messenger 68, June 1992, p. 45).

1.3 mm Bolometer

The SEST bolometer was designed at MPIfr, Bonn. A similar bolometer is described in Kreysa (1990, "From Ground-Based to Space-Borne Sub-mm Astronomy", Liege, Belgium, ESA SP-314, p. 265). The bolometer has a center frequency of 236 GHz (1.27 mm) and a bandwidth of about 50 GHz. The sensitivity is 200 mJy $s^{-1/2}$ $beam^{-1}$ (in one second a one sigma noise of 200 mJy is reached). It consists of a Germanium element inside a ^3He cryostat cooled to about 0.3 K. The hold time is about 36 h, but for operational reasons the recycling of the ^3He and and refill of ^4He and Nitrogen is done every 24 h, a process that takes about 4 h.

The bolometer is accessed by removing a remotely controlled mirror in the quasi-optical arrangement (Fig. 2.1.). It has its own focal plane chopping mirror. An ecosorb load can be inserted in one of the beams for calibration purposes. The beam separation is nominally 70", but can be adjusted to 120". In case of bad weather (unstable atmosphere) during bolometer observations it is possible to switch to spectral line observations within 5 to 10 minutes.

2.2.4 Spectrometers

Three Acousto Optical Spectrometers (AOSs) are used as backends for spectral line and sometimes continuum observations. These AOS:s were built at the University of Cologne and their general design characteristics have been described in Schieder et al. (1989, Experimental Astronomy 1, p. 101).

Two of the AOS's cover a wide band (1 GHz), with lower resolution (LRS = Low Resolution Spectrometer), the third one covers a narrow band (86 GHz), but has a higher resolution (HRS = High Resolution Spectrometer). Their characteristics are described in Table 2.

Table 2.4: Spectrometer characteristics

	HRS	LRS1	LRS2
Total bandwidth	86 MHz	995 MHz	1086 MHz
Number of channels	2000	1440	1600
Channel separation	43 kHz	0.69 MHz	0.68 MHz
Resolution	80 kHz	1.4 MHz	1.4 MHz
Noise bandwidth/channel	105 kHz	1.8 MHz	1.8 MHz

2.2.5 Combinations of receivers and spectrometers

It is possible to observe with two spectrometers simultaneously. For single receiver operation the HRS and one LRS can be used simultaneously and the HRS can be placed anywhere within the band of the LRS. During dual receiver operation the two polarization channels of the 3 mm receiver can be used at the same time or one of the 3 mm polarization channels can be used together with the 1.3 mm receiver. In this case the two LRS's can be used simultaneously to cover as large a band as possible for each receiver, but at lower resolution. To obtain higher resolution it is possible to split the HRS into two parts and connect each part to one receiver. The HRS then has a bandwidth of 43 MHz per receiver. Also one of the LRS's can be split into two parts (2 x 500 MHz) and each part can be connected to one receiver.

Note that the 0.8 mm receiver can not be used simultaneously with another receiver.

2.2.6 The telescope and instruments control system

The control of the SEST and instrumentation is done by two networked minicomputers: a Hewlett Packard 1000/A900 and an HP1000/A600 running under the operating system RTE-A. The A900, the main computer, is used for general purpose instrument control and data reduction. The A600 (a smaller version of the A900) is dedicated to data acquisition from the AOSs. The two computers are linked by ethernet.

Each spectrum is stored as an ordinary disc file on the A900. Hardcopies of graphics and text is obtained through a line printer, an eight pen plotter, or a small ThinkJet printer.

2.2.7 Export Tape Formats and Backups

A standard computer tape drive is available to store data on tape. The tape densities are 800, 1600, or 6250 bpi. Spectral line data is normally transported in FITS format. Tapes can also be written in HP format (FST and TAR).

Continuum (bolometer) scans are written in ASCII format.

The observers are recommended to do a backup of their data after each observing shift. When the observations are finished, the data will be backed up on a SEST archive tape which is kept at the telescope for several years.

2.3 3.6 m telescope

2.3.1 Introduction

The 3.6 m telescope was commissioned in 1977. The telescope has a horseshoe/fork mounting. It was designed with interchangeable top-units allowing change over of secondaries to go from prime to Cassegrain or Coudé focus. An f/35 wobbling secondary unit is available for infrared work. Change over of equipment at the Cassegrain focus takes between 3 and 4 hours. The telescope is used nearly exclusively at Cassegrain with the optical or IR top rings. The CES (see Section 3.8) can be fed from the 3.6 m by an optical fibre. The telescope employs the standard ESO TCS (Telescope Control System). The r.m.s. pointing errors are better than 10″ over the whole sky when an up-to-date pointing model is loaded. Observers should bring accurate coordinates and well prepared finding charts.

2.3.2 Equipment assembly and testing

A room is set aside (#407, in the 3.6 m building) which may be used by visitors to assemble and test their equipment before mounting on the telescope.

2.4 3.6 m Cassegrain

(f/8.09, scale 7.12 arcsec mm^{-1})

The Cassegrain focus is shown schematically in Fig. 2.2. The equipment available at the Cassegrain focus is given in Table 2.2. The telescope has a large Cassegrain cage in which the observer can stand and control the equipment if absolutely necessary. Riding in the cage at best is uncomfortable, specially at low altitudes and can also be dangerous. VAs

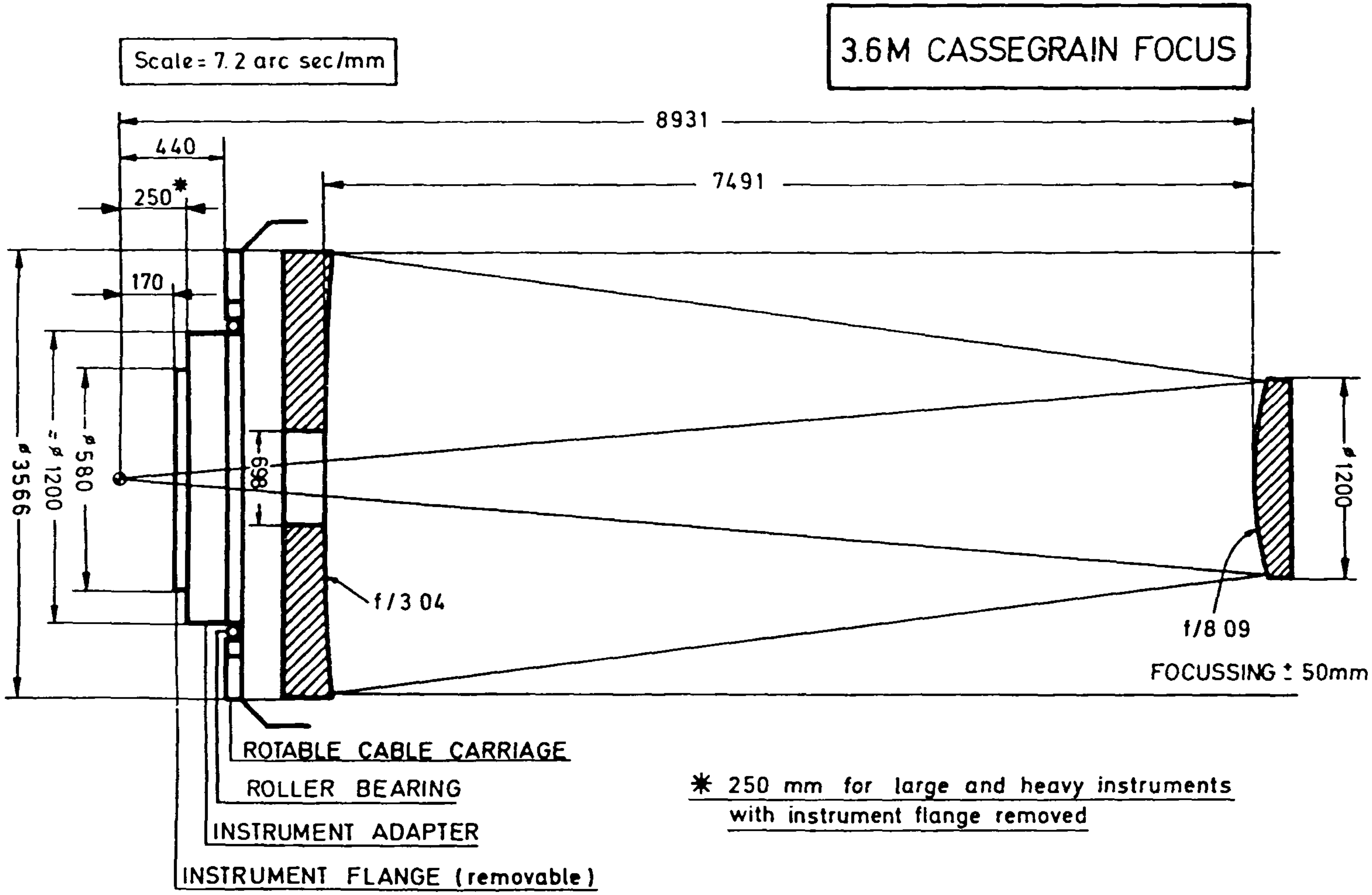


Figure 2.2: Cassegrain focus of the 3.6 m telescope

who bring their own equipment should make every effort to remote control the equipment via CAMAC.

The distance between the Cassegrain adapter ring and the cage floor is 175 cm. However, symmetrically placed either side of the optical axis on the cage floor are two rails, 90 cm apart and 4 cm high which are used with a small trolley to mount heavy equipment.

2.4.1 Cassegrain adapter and fields of view

Equipment is mounted on an adapter attached to the telescope which contains a system of movable mirrors and an integrating TV system for field identification and guiding. The field of view is displayed on a TV monitor in the control room and can also be sent to a small TV in the Cassegrain cage. Levels of magnification are as follows:

Field	Approximate field in arcmin	Scale
center field	3×2.5	$1' = 48$ mm
slit view	3×2.5	$1' = 48$ mm
guide probe	1.3×1	$1'' = 3.2$ mm

Each field can be requested via a display console in the control room. These figures do not apply to the f/35 IR configuration.

2.4.2 Integrating TV system

An integrating CCD camera is available. Normally, without integration V= 18 mag stars are easily seen; and with integration the limiting magnitude is about V= 21 mag. These numbers are approximate and depend on the seeing and presence of moon, etc. A filter wheel (see Table 2.5) is mounted in front of the camera and this is particularly useful to offset the sky brightness during moonlit periods or near twilight. The integrating CCD camera is not used with the f/35 IR configuration.

Table 2.5: Filters for the 3.6 m integrating TV system

Color	Filter	Central wavelength (nm)	Approximate $\Delta\lambda$ nm
Blue	GG 435 + BG 12	455	100
Green	OG 515 + BG 18	550	100
Red	RG 665	710	100
White	None	—	—

2.4.3 Autoguider

An autoguider system developed by ESO has been implemented at the 3.6 m Cassegrain focus (similar systems are used at the NTT, 2.2 m, 1.4 m CAT, and the 91 cm Dutch). To the observer it appears as a *software* box with cross hairs on the guiding television which can be adjusted in size around any suitable guide star. The system effectively balances the flux received in the four quadrants of the "box", and is capable of guiding on objects down to ~ 17 mag.

2.4.4 Instrument rotation

Instrumentation can be rotated at Cassegrain focus by setting the desired angle at the console in the control room. Angles are accurate to ~ 0.°1.

2.5 NTT — The 3.5 m New Technology Telescope

(f/11, scale 5.21 arcsec mm^{-1})

In March 1989, the 3.5 m New Technology Telescope (NTT) saw "first light". CCD frames were obtained on which stellar images had FWHM diameters of 0.″33, indicating the excellent imaging quality of this telescope. A schematic diagram of the NTT is shown in Fig. 2.3.

The 3.5 m NTT is of alt-az design and resides in a rotating building. The control room, and therefore also the observer, turns with the telescope!

The telescope chamber is ventilated by a system of flaps which optimize the air flow across the NTT minimizing the "dome" and mirror seeing. All motors in the telescope environment are water cooled to prevent heat input to the building.

The primary mirror is actively controlled to preserve its figure at all telescope positions. The secondary mirror position is also actively controlled in three dimensions. This fully optimizes the imaging quality of the NTT.

The NTT is of a very rigid construction due to the reduced mass of the primary mirror and telescope structure compared with classical telescopes. This results in very accurate pointing of ~ 1.″5 r.m.s. over the whole sky. Tracking accuracy at 0.″1 matches the overall image quality of 80% energy in 0.″15 diameter.

The NTT has two Nasmyth focus platforms to mount two sets of instruments simultaneously. To switch from one to the other, a 45° third flat mirror is rotated by 180°. Change over therefore takes little time.

Table 2.6 lists the main parameters characterizing the NTT.

The telescope control system allows full remote control of all functions, either from the control room or from its equivalent in Garching. It has a sophisticated input catalogue

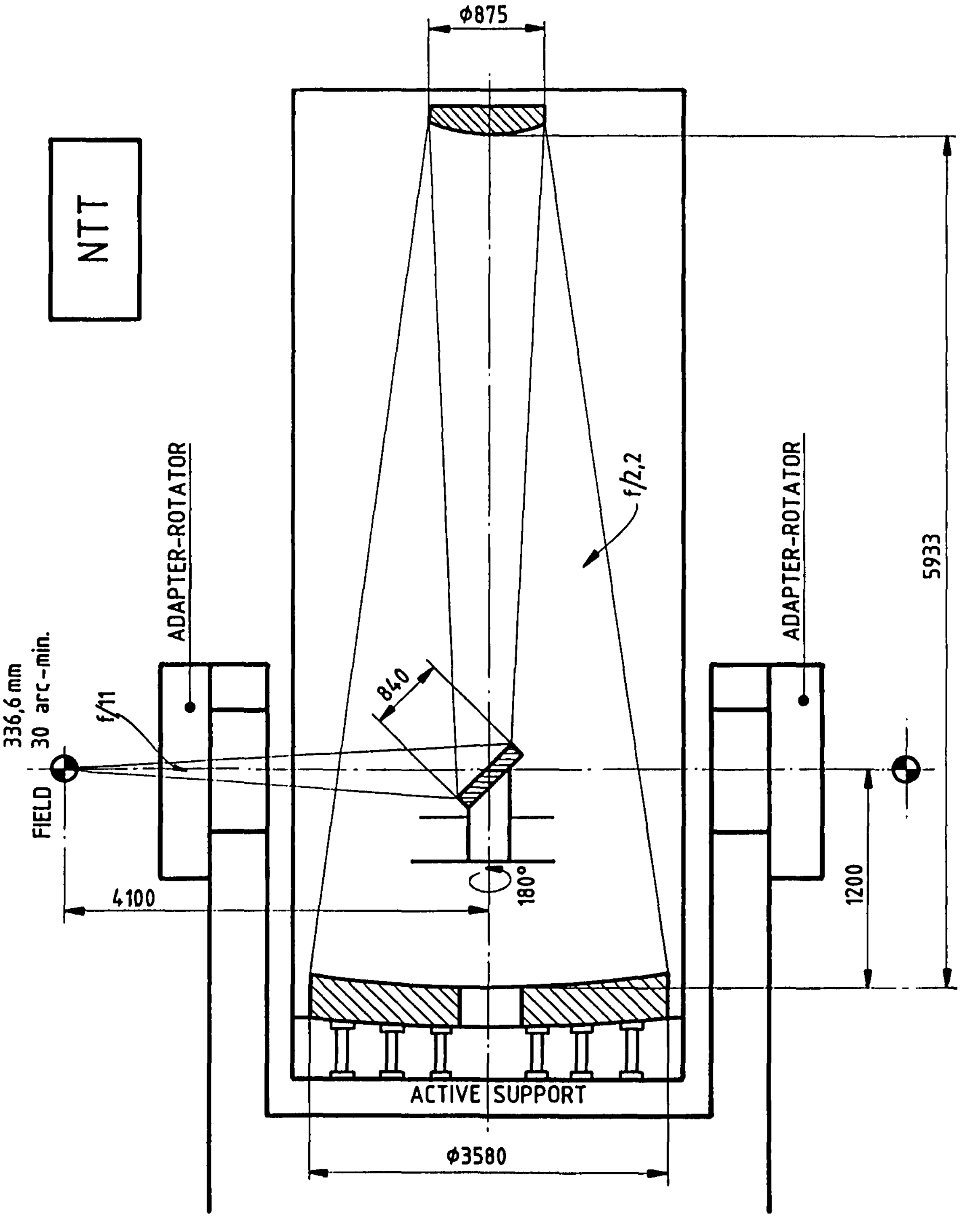


Figure 2.3: Schematic diagram of the 3.5 m NTT

system.

Table 2.6: 3.5 m NTT main parameters

Primary mirror	:	3.58 m diameter, thin meniscus actively controlled
Focal ratio	:	f/2.2
Nasmyth focal ratio	:	f/11
Imaging scale	:	5.″21 mm^{-1}
Imaging quality	:	80% energy in 0.″15 diameter in all telescope positions

2.6 The 2.2 m telescope

(f/8, scale 11.65 arcsec mm^{-1})

The 2.2 m telescope at La Silla has been in operation since early 1984.

The telescope is on indefinite loan to ESO from the Max Planck Gesellschaft and 67% of the observing time is available to ESO observers. Operation and maintenance of the telescope is the full responsibility of ESO. The telescope is a Ritchey-Chretien design and is shown schematically in Fig. 2.4.

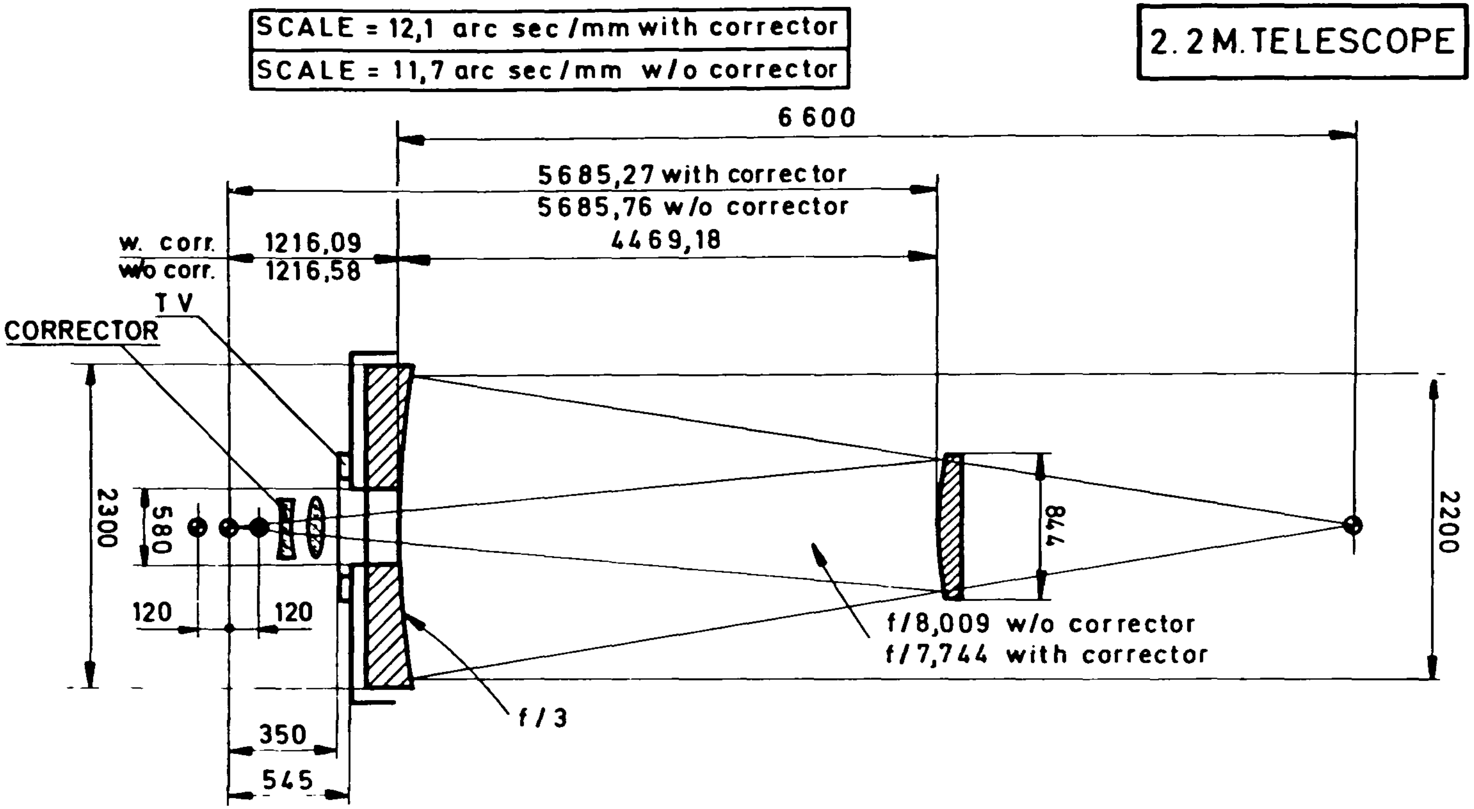
The standard ESO TCS and autoguider are used for this telescope. The available instruments are listed in Table 2.2. Instruments can only be rotated manually. A Vernier scale is mounted on the adapter to find the instrumental angle. IHAP and the full range of peripheral devices (Ramtek, monitor, plotter, hardcopy device, printer) are available as at the 3.6 m telescope. A MIDAS workstation with peripherals is also available at the telescope connected to IRAC 2 and to EFOSC 2 for on-line data processing.

2.7 The 1.5 m Danish telescope

(Cassegrain f/8.46, scale 15.7 arcsec mm^{-1})

The 1.5 m Danish telescope has been in regular use since November 1979. It is owned by the University of Copenhagen and ESO receives approximately 50% of the observing time, generally every other month. During such periods, the telescope is used mostly with the CCD camera.

The telescope has an off-axis mount and the optics are of a Ritchey-Chretien design. It is shown schematically in Fig. 2.5. It is controlled by an ESO developed TCS system. The pointing accuracy is $\sim 10''$. A detailed users manual on the operation of the telescope and its auxiliary equipment can be obtained by writing to the Visiting Astronomers Section, Garching.



MECHANICAL FOCUS RANGE = 240, F 315 IS FIXED, WHEN TV ATTACHMENT IS MOUNTED. CLEARANCE BETWEEN FORK AND INSTRUMENT FLANGE 1645 (1415 WITH TV ATTACHMENT) INTERFACE OF INSTRUMENT FLANGE
SYSTEM : RITCHEY - CHRETIEN

Figure 2.4: Schematic layout of the 2.2 m telescope

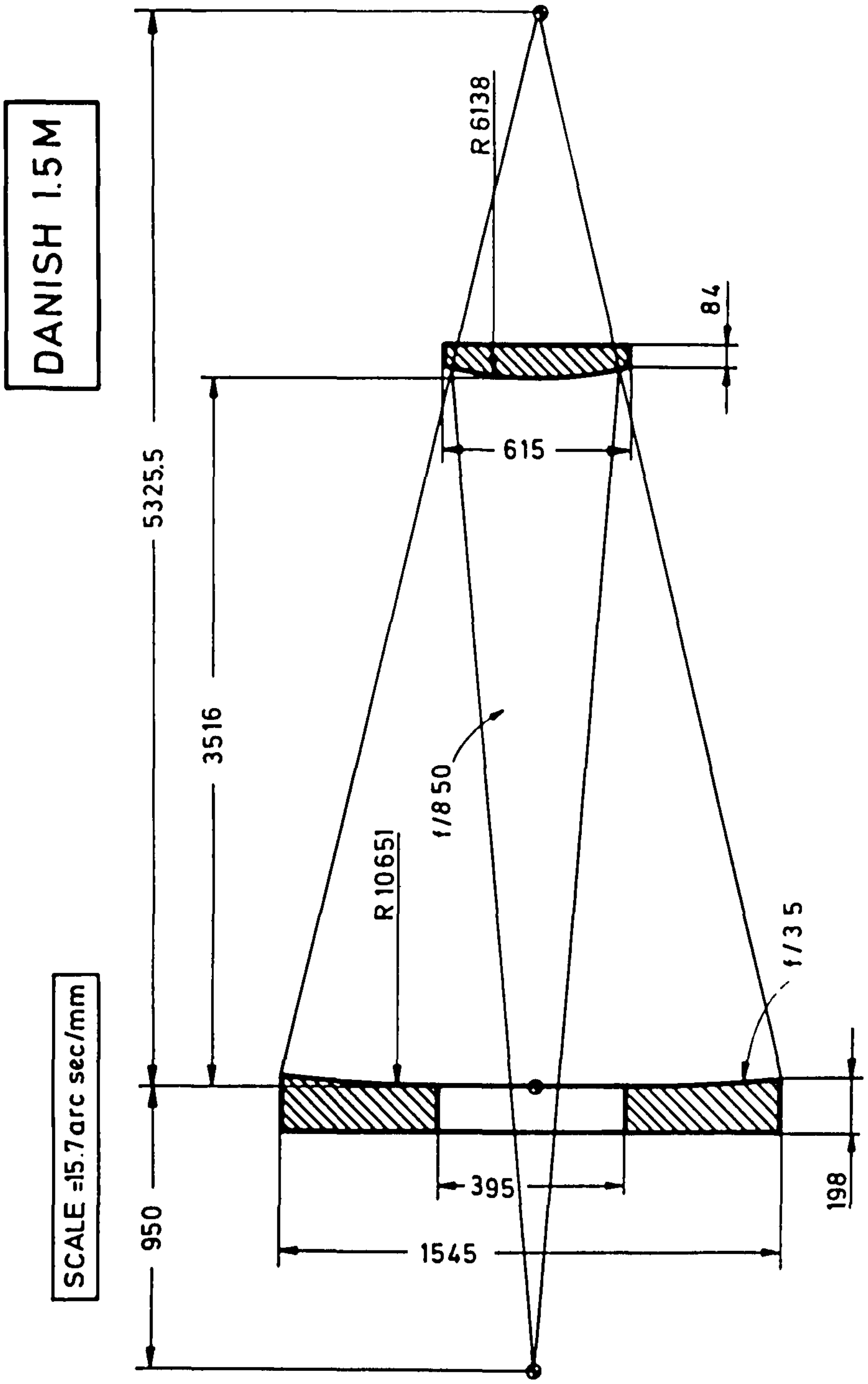


Figure 2.5: Schematic layout of the 1.5 m Danish telescope

A microprocessor based safety system protects the telescope and its auxiliary instrumentation against collisions with fixed parts such as the telescope base. A later installation of a spacer ring beneath the Cassegrain adapter has further limited the sky coverage. As the telescope can be used either west or east of the base, there are two sets of limits; they are, however, symmetric. Telescope operation west of the base has the advantage that tracking (but not presetting) can be done into part of the new "danger" zone; the observer may override a first warning signal.

Starting August 1993 the 1.5 m Danish telescope will be completely overhauled. A new TCS will be installed based on VME Local Control Units and Unix workstation. A standard ESO autoguider will be implemented. The instrument adapter wil be replaced and the standard instrument will be DFOSC, a copy of EFOSC with some modifications.

Please get in contact with the Visiting Astronomers Section in Garching for further details.

A description of the new system once completed and tested will be posted in the electronic Bulletin Board.

2.8 The 1.5 m ESO telescope

(Cassegrain f/14.9, scale 9.0 arcsec mm^{-1})
(Coudé f/31.4, scale 4.29 arcsec mm^{-1})

The telescope is essentially a twin of the 1.5 m at l'Observatoire de Haute Provence. It is mounted in an English cradle and can be used at f/14.9 Cassegrain or f/31.4 Coudé. The two optical layouts are shown schematically in Figs. 2.6 and 2.7.

This mounting prevents, at declinations above +15° or below −40°, objects to be observed after or before the meridian depending on the telescope position being respectively east or west of the pier.

Changing over the telescope from one side to the other requires rebalancing and takes about 1 hour; therefore it is not recommended during the night.

There is a moving floor under the telescope, allowing easy access to the instruments mounted at Cassegrain.

The TCS system is based on an IBM PC compatible micro computer and operates in a similar manner to TCS at the other telescopes. Objects are entered into a catalogue which can be stored on hard disk. MIDAS and IHAP are available for on-line data reduction.

The Cassegrain focus can support equipment weighing up to 150 kg with a centre of gravity up to one metre from the back plate.

2.9 CAT — The Coudé Auxiliary Telescope

(f/32.3, scale 4.54 arcsec mm^{-1})

The CAT, shown schematically in Fig. 2.8, was designed to feed the Coudé Echelle Spectrometer (CES). The CAT stands on a 24 m high pillar alongside the 3.6 m telescope building and is connected to the 3.6 m coude room via an 11 m long tube. The telescope has a clear aperture of 1.4 m. It has an alt-alt mounting producing field rotation during observations. The telescope optics are of the Dahl-Kirkham type with an ellipsoidal primary and a spherical secondary. The third mirror is a Nasmyth focus mirror which rotates at half tube speed in order to maintain a fixed light beam in space. The pointing restrictions are shown in Fig. 2.8.

The CAT/CES combination is designed to have a high light throughput and, for this reason, an optimized red or blue path can be selected including the telescope secondary mirror, two focal reducer elements, predisperser collimator, and main collimator.

The system is f/120 which allows the beam to pass through the connecting tube, but uses a focal reducer to produce an f/32.3 beam to feed the CES.

Acquisition is done using a 15 cm finder telescope with intensified TV and an intensified slit viewer which is also used for the auto-guider. The slit viewer has two selectable field sizes. One is used for field recognition, the other for autoguiding on the slit.

2.10 The 1 m telescope

(f/13.6, scale 14.58 arcsec mm^{-1})

This fork-mounted 1.0 m telescope is shown schematically in Fig. 2.10 and is used only at Cassegrain focus.

The TCS is similar to that on other ESO telescopes.

The telescope can carry equipment weighing up to 150 kg at the Cassegrain focus. The clearance through the fork is 1.2 m.

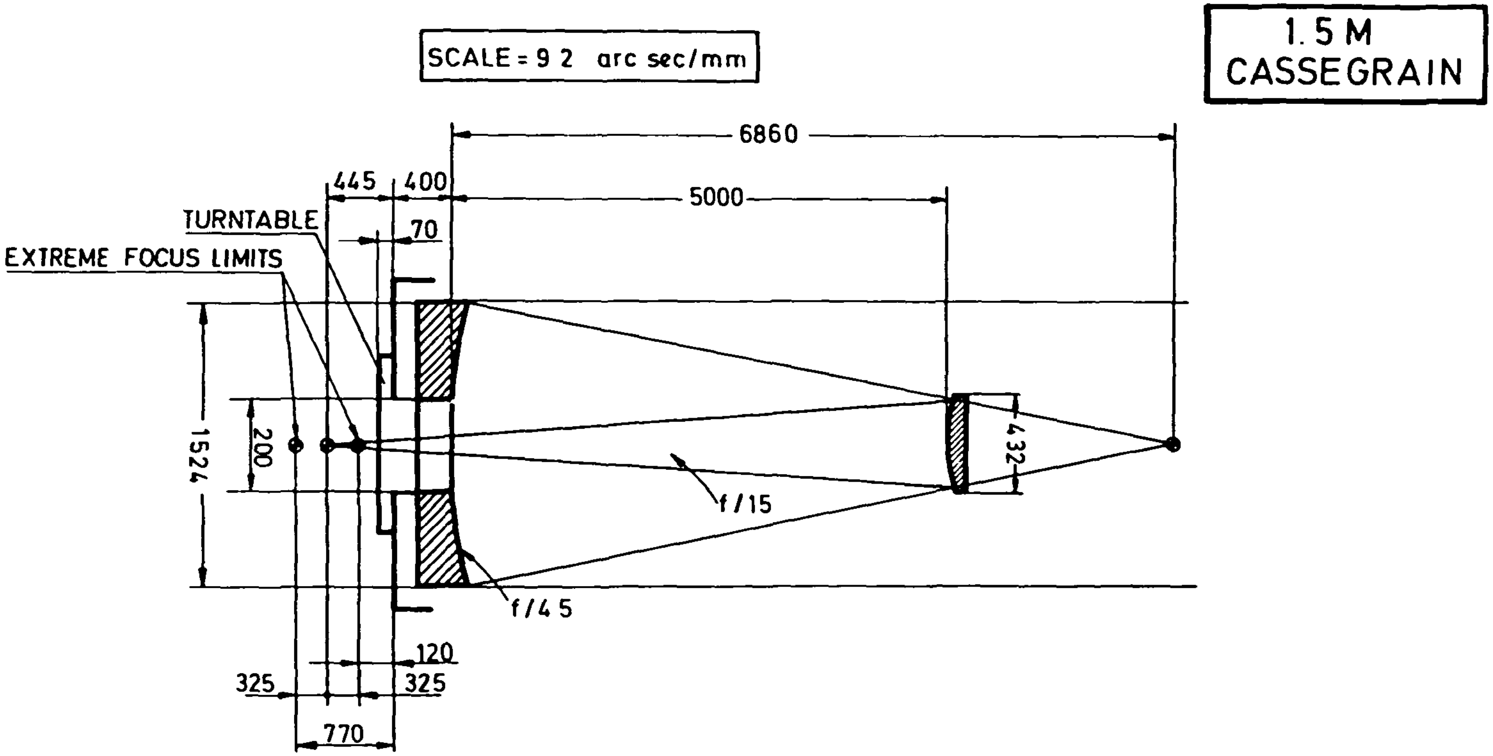
At the 1 m telescope there is a single channel visual photometer and an IR photometer with InSb and bolometer detectors, as listed in Table 2.2.

2.11 The 1 m Schmidt telescope

(f/3, scale 67.5 arcsec mm^{-1})

The 1 m Schmidt telescope was designed basically after the Hamburg Observatory Schmidt. Its principal job was to survey the southern hemisphere. For this reason, the plate scale, 67.5 arcsec mm^{-1}, was chosen to match that of the Palomar Schmidt. Time is available for VAs' programmes. These are always carried out by ESO staff.

The telescope is mounted in a fork and shown schematically in Fig. 2.11. The f/3 primary is 1620 mm in diameter, and the telescope has a free aperture of 1 m. Guiding is achieved



INTERFACE OF TURNTABLE ,SEE DRAWING II.1.FIG.2,2.1.
MECHANICAL FOCUS RANGE = 650

Figure 2.6: The 1.5 m ESO telescope: Cassegrain focus

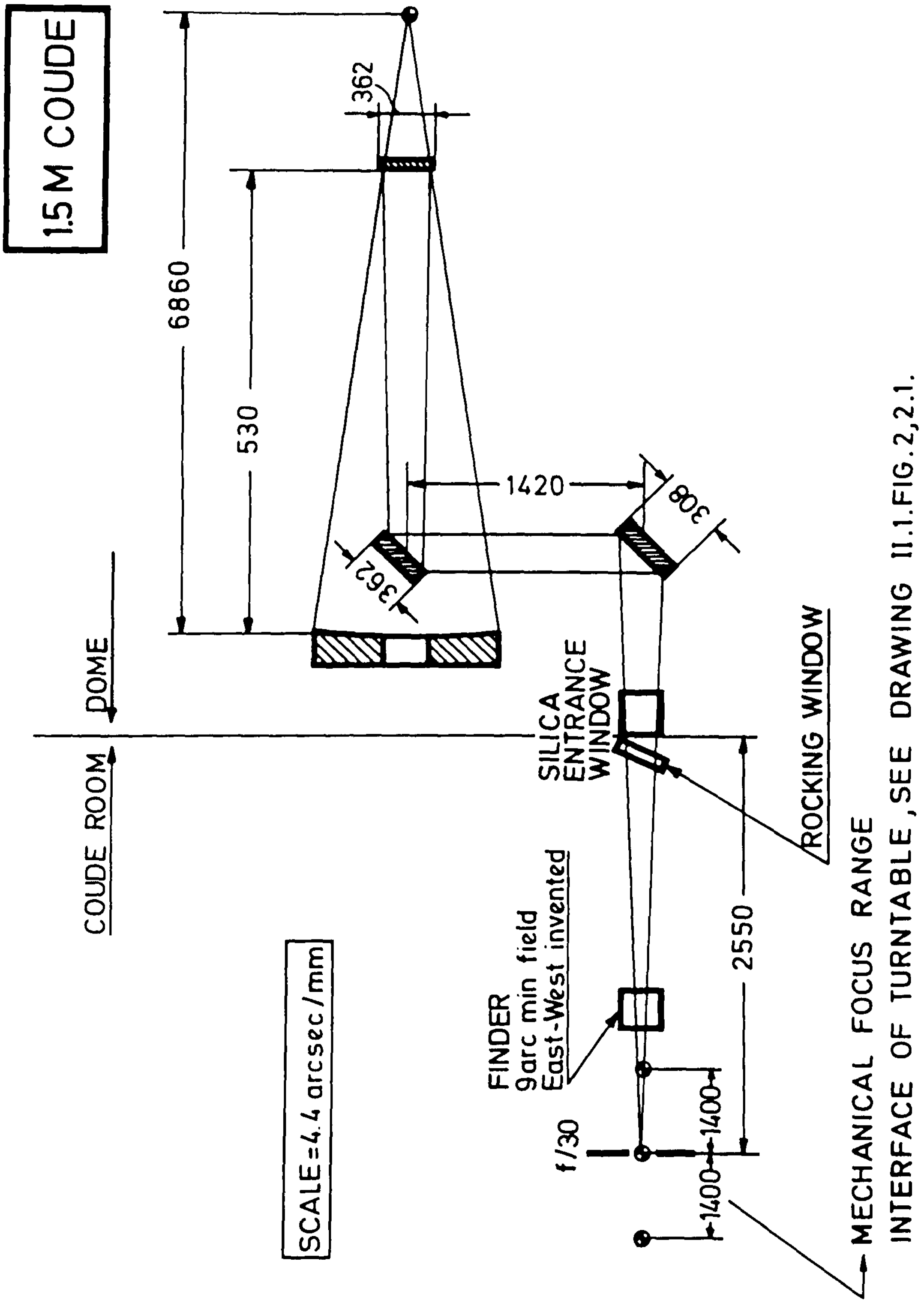


Figure 2.7: The 1.5 m ESO telescope: Coudé focus

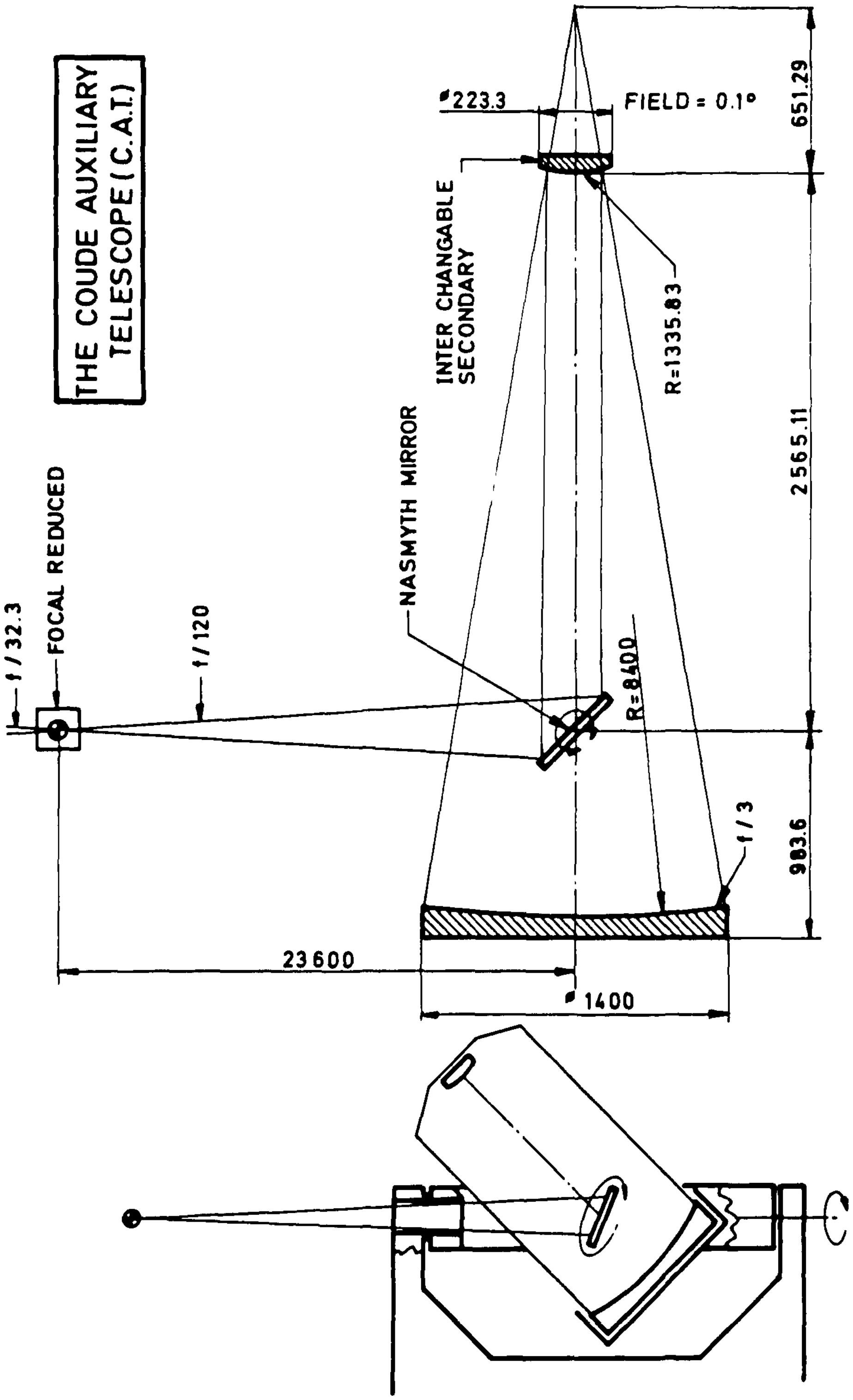


Figure 2.8: The 1.4 m CAT

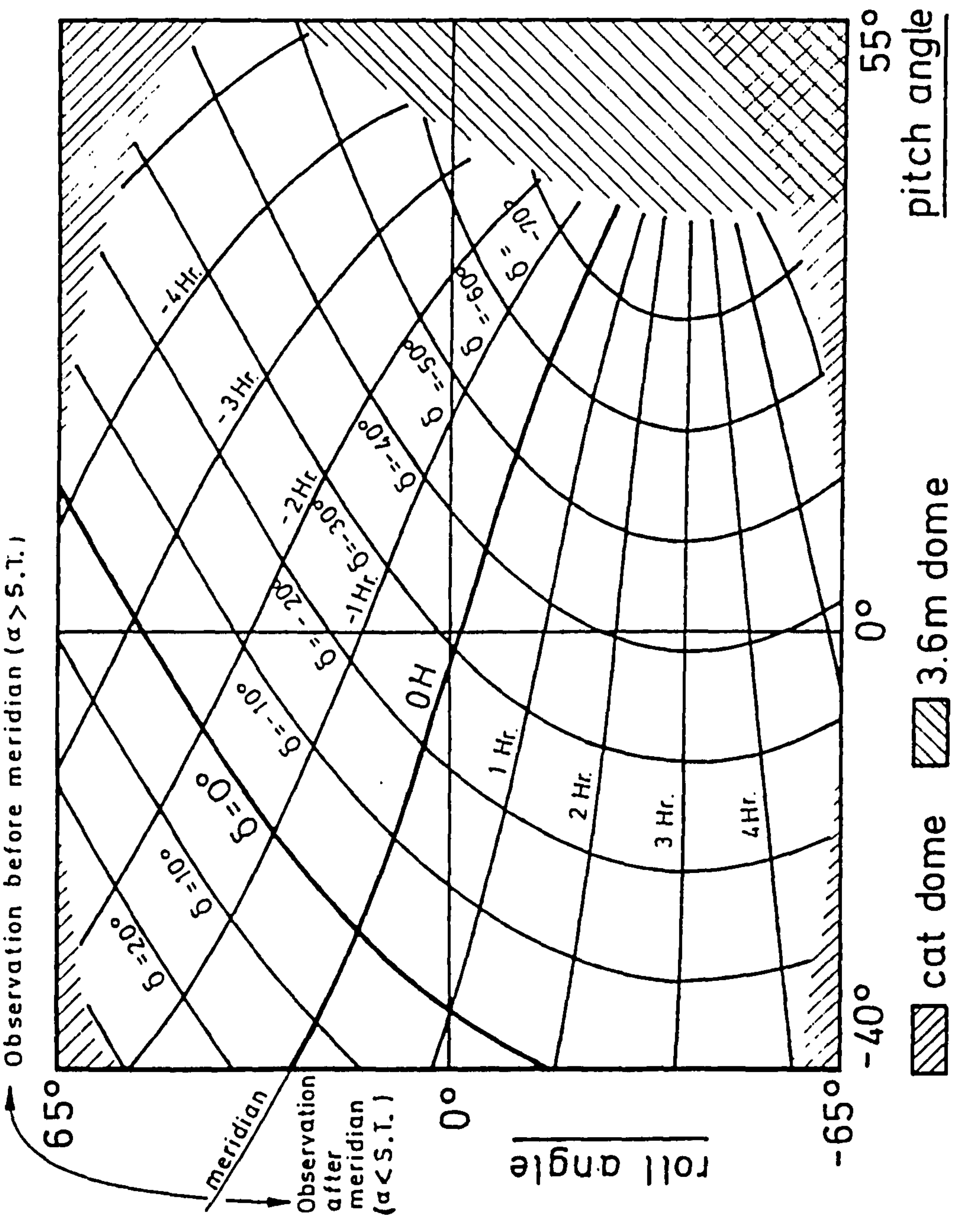
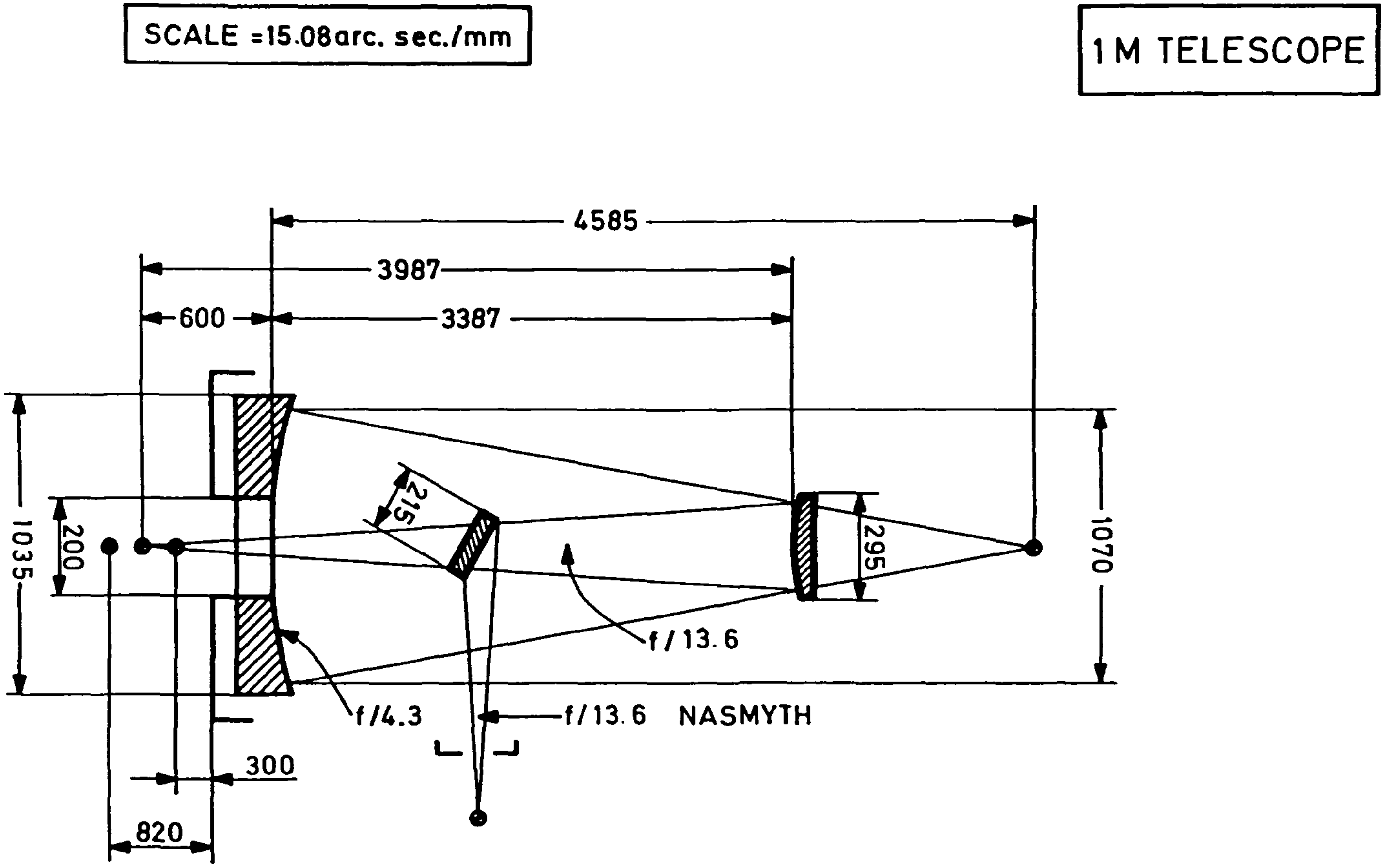


Figure 2.9: Pointing restrictions of the CAT



MECHANICAL FOCUS RANGE = 520
CLEARANCE BETWEEN FORK AND INSTRUMENT FLANGE 1100
INTERFACE OF INSTRUMENT FLANGE, SEE DRAWING II.1.FIG.3,3.1.

Figure 2.10: The 1 m telescope

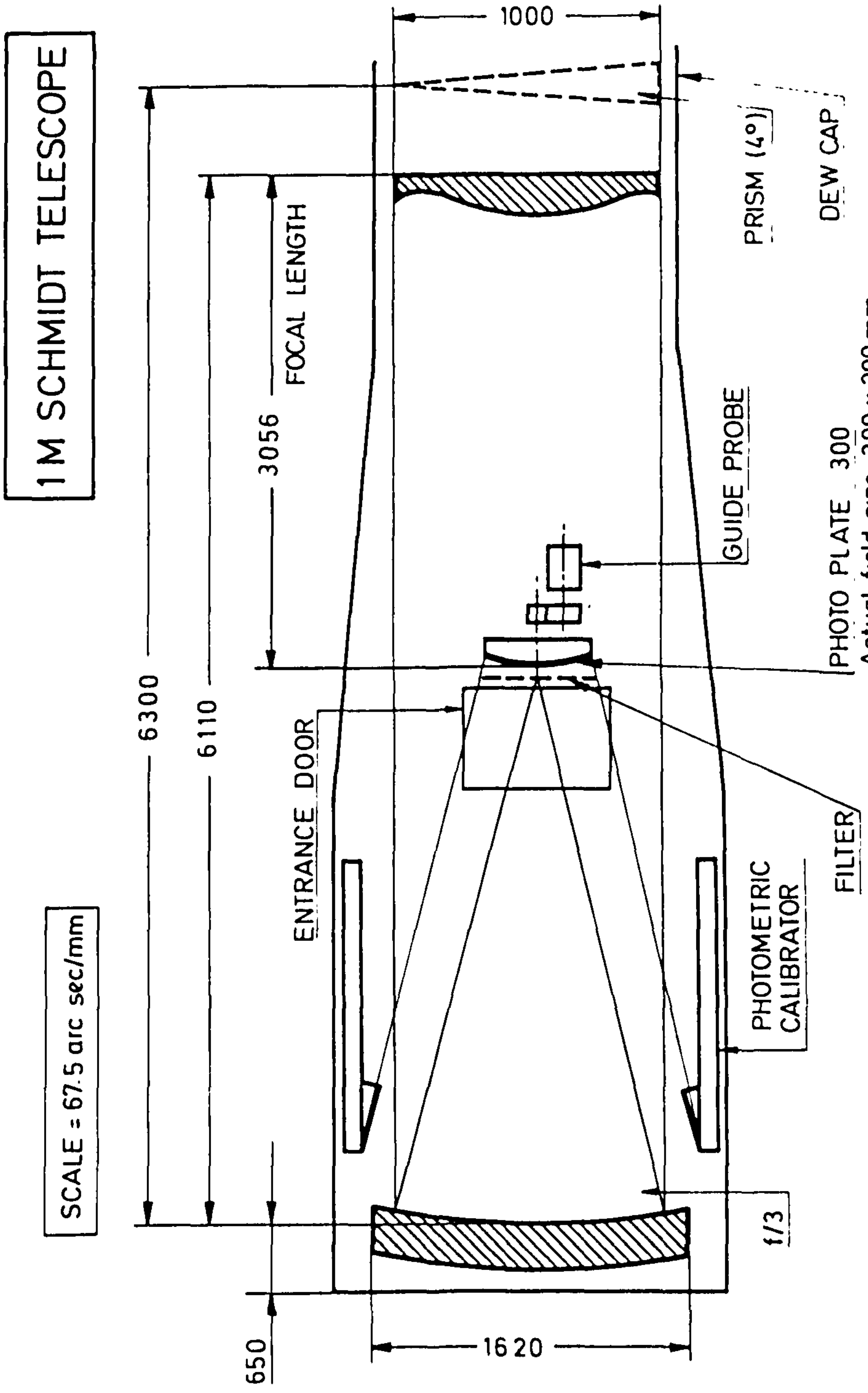


Figure 2.11: The 1 m Schmidt telescope

by use of a TV guide probe with autoguider.

The plate size is 290 × 290 mm^2, subtending 5° × 5° on the sky.

The following filters can be mounted: UG1, GG385, GG495, GG475, RG630, RG665, RG10, BG12 and OG550. These all have dimensions of 340 × 340 × 2 mm^3. In addition, some interference filters are available. Their details are given in Table 2.7.

Table 2.7: ESO Schmidt interference filters

λ Centre (nm)	$\Delta\lambda$ (nm)	Transmission (%)	Effective Refractive Index
	6 inch diameter, 4 mm thick		
447	9.0	35	1.35
467	9.0	35	2.0
502	9.0	35	2.0
	6 inch diameter, 10 mm thick		
673	4.4	55	—
657	5.2	54	—

There is a 1 m diameter objective prism. It has a 4° angle and gives a dispersion of 45 nm mm^{-1} at Hγ. The limiting magnitude is about 15, with a widening of 0.2 mm.

2.11.1 Photometric wedge

A 144 mm diameter photometric wedge is available which is mounted in front of the Schmidt corrector on the north-east corner. The wedge is made of UBK7 glass and has a refracting angle of 60″ producing an image separation on the plate of 0.5 mm or 31″. The effective surface area of the Schmidt corrector plate, taking into account vignetting of the wedge, its support and spider arms is 5745 cm^2 giving a magnitude difference Δmag $\simeq$ 3.96. This difference may be increased by stopping down the wedge. The wedge can be mounted and dismounted in a matter of minutes and, as its focal ratio is f/21.2, the effects of defocusing can be considered negligible. The usable unvignetted area of the plate using this device falls in a radius of 154.9 mm, and within the area a portion of the NE quadrant is also lost due to vignetting by the prism mounting. For a full description see Muller, A.B., 1980, The Messenger No. 22, p. 18.

2.11.2 Densitometric calibration

Two sets of densitometric spots can be exposed on the plates as indicated in the Figure 2.12. The relative intensities of these spots are given in Table 2.8.

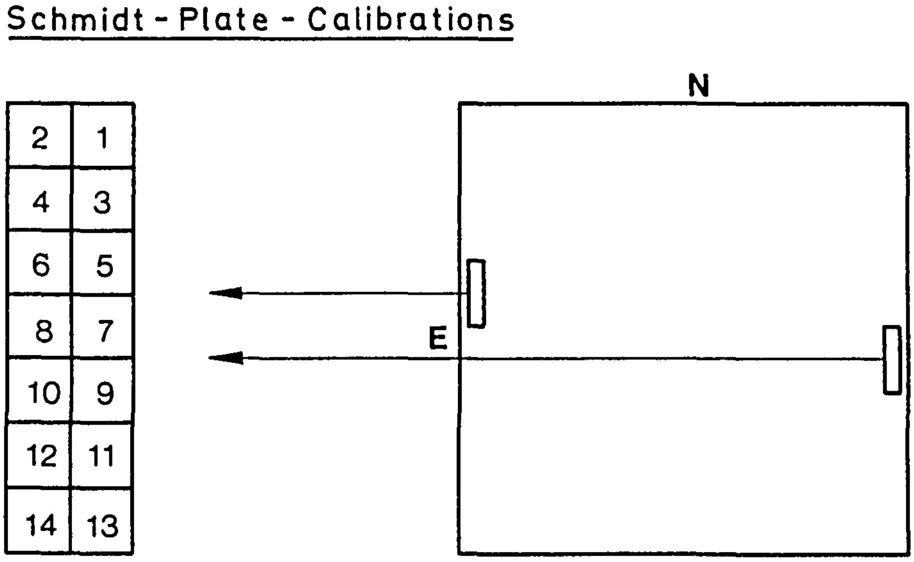


Figure 2.12: Location of Schmidt densitometric spots

2.11.3 Multiexposure device

This device consists of a pair of disks mounted on the same axis in front of the photographic plate. Each disk has a series of apertures and only one aperture of each disk coincides with an aperture in the second disk at a given position. The device acts effectively as a photographic mask allowing a series of small fields, presently 45 × 47 arcmin, to be photographed in three circular zones on a single plate. The plate is divided into 36 equal areas.

Originally the device was designed in order to systematically survey a large number of galaxies to make an early identification of a new supernova. This programme has recently been re-started. This device allows 36 fields to be photographed on the same plate without time lost due to plate changes; it also ensures that all exposures are taken on the same emulsion and developed under identical conditions; it further results in a considerable saving in photographic materials. Another obvious use is for visitors who wish to have a standard photometric sequence on the same plate. The disks are mounted 38 mm in front of the photographic plate and this produces some vignetting at the edges of each field. The vignetting starts about 7 mm from the field edges. However, if the exposure time is well chosen, 15th magnitude stars can be seen to about 2 mm from the field edges. The instrument takes approximately 45 min to mount and dismount and for this reason it cannot be changed during the night. The visitor should then provide sufficient objects in order to fill one night. For additional details see Müller, A.B., 1979, The Messenger No. 19, p. 29.

Table 2.8: Relative densities of Schmidt densitometric wedges

Spot	East	West
1	.00	.00
2	.09	.08
3	.20	.20
4	.28	.28
5	.37	.38
6	.43	.44
7	.54	.53
8	.59	.59
9	.70	.71
10	.74	.74
11	.86	.86
12	.89	.89
13	1.01	1.02
14	1.02	1.04
r.m.s.	±0.003	±0.005

2.12 The 0.9 m Dutch telescope

(f/13.75, scale 16.4 arcsec mm^{-1})

The telescope is the property of the "Stichting het Leids Sterrewacht Fonds" in the Netherlands. Since 1958, it has been in operation at the Leiden southern station site near Hartebeespoortdam, South Africa. During 1978–1979 it was removed and re-erected at La Silla. The telescope schematics are shown in Figure 2.13.

ESO receives 70% of the available observing time.

The telescope is a prototype for the 1 m ESO and has Dahl–Kirkham optics. It is fork-mounted and has a Cassegrain focus. Its usable uncorrected field is $3'$ in diameter. Instruments should be less than 83 cm in length to pass through the fork, and not be heavier than 100 kg.

The instrument available is the adapter with CCD for direct imaging (see Section 3.16).

The pointing of the telescope is of the order of $10''$ and by offsetting from a nearby star, it can be as good as $5''$. Limit switches are fitted in declination, hour angle, and elevation.

The dome floor is fixed. The dome rotation is manual but will be made automatic in the course of 1993. A building connected to the dome houses a control room, store room, computer room and toilet.

The TCS is similar to that used on the other telescopes. Moving objects such as comets and asteroids can be tracked with the autoguider.

2.13 The 0.5 m ESO telescope

(f/13.6, scale 27.5 arcsec mm^{-1})

This fork mounted 50 cm telescope, shown schematically in Fig. 2.14, is very similar to the 0.5 m Danish. It is computer controlled but due to the backlash and a slight sinusoidal error, pointing accuracy is not better than $\approx 15''$.

The TCS can store up to 200 star coordinates and precess from any epoch.

Two HP computers are used in the system, one controls the telescope, the other is used for the photometer acquisition program. Both the data acquisition and telescope control are operated through a single keyboard/display in the dome.

Interface of equipment is made through CAMAC modules.

Equipment available is given in Table 2.2.

Data are recorded on magnetic tape or line printer. The telescope can carry a maximum weight of 90 kg at the Cassegrain focus. The clearance through the fork is 78 cm.

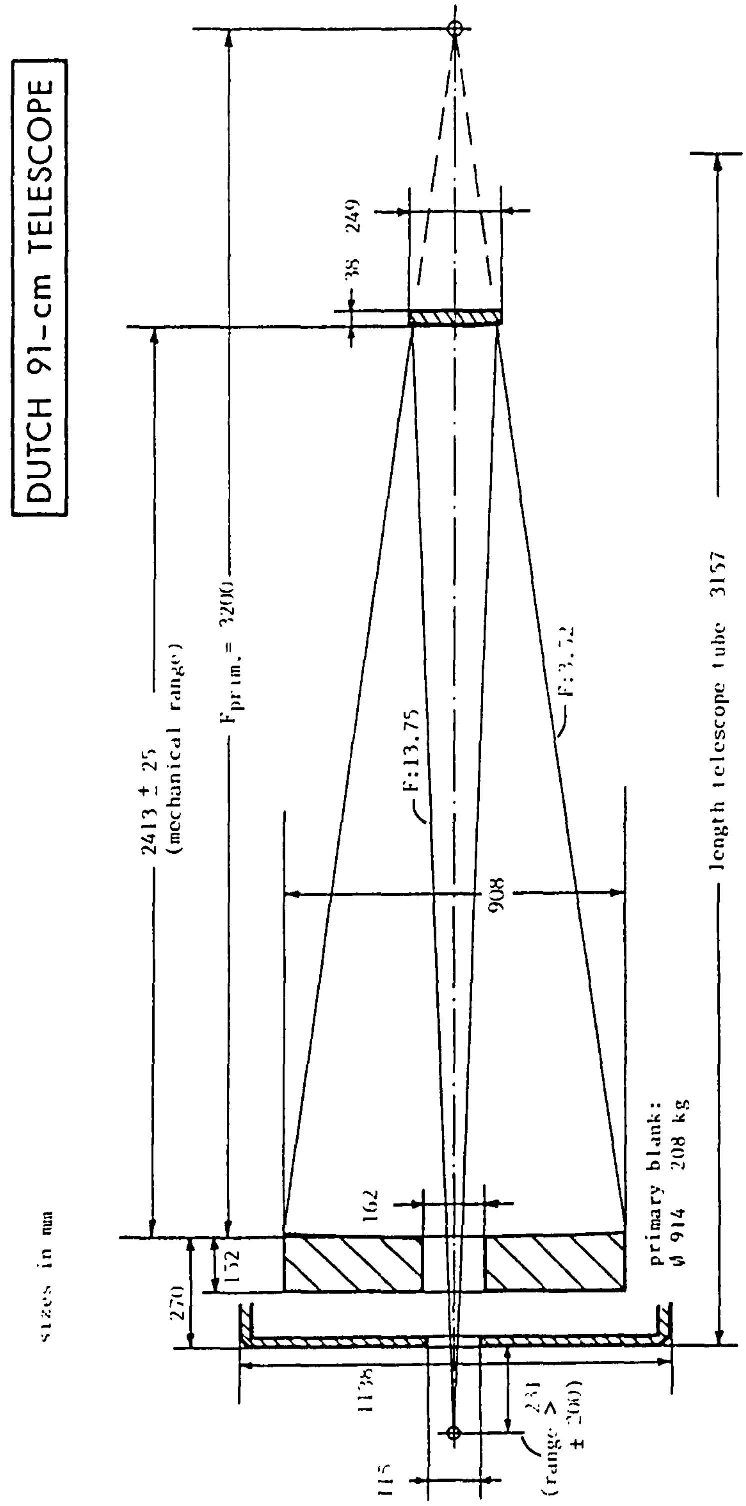


Figure 2.13: The 0.9 m Dutch telescope

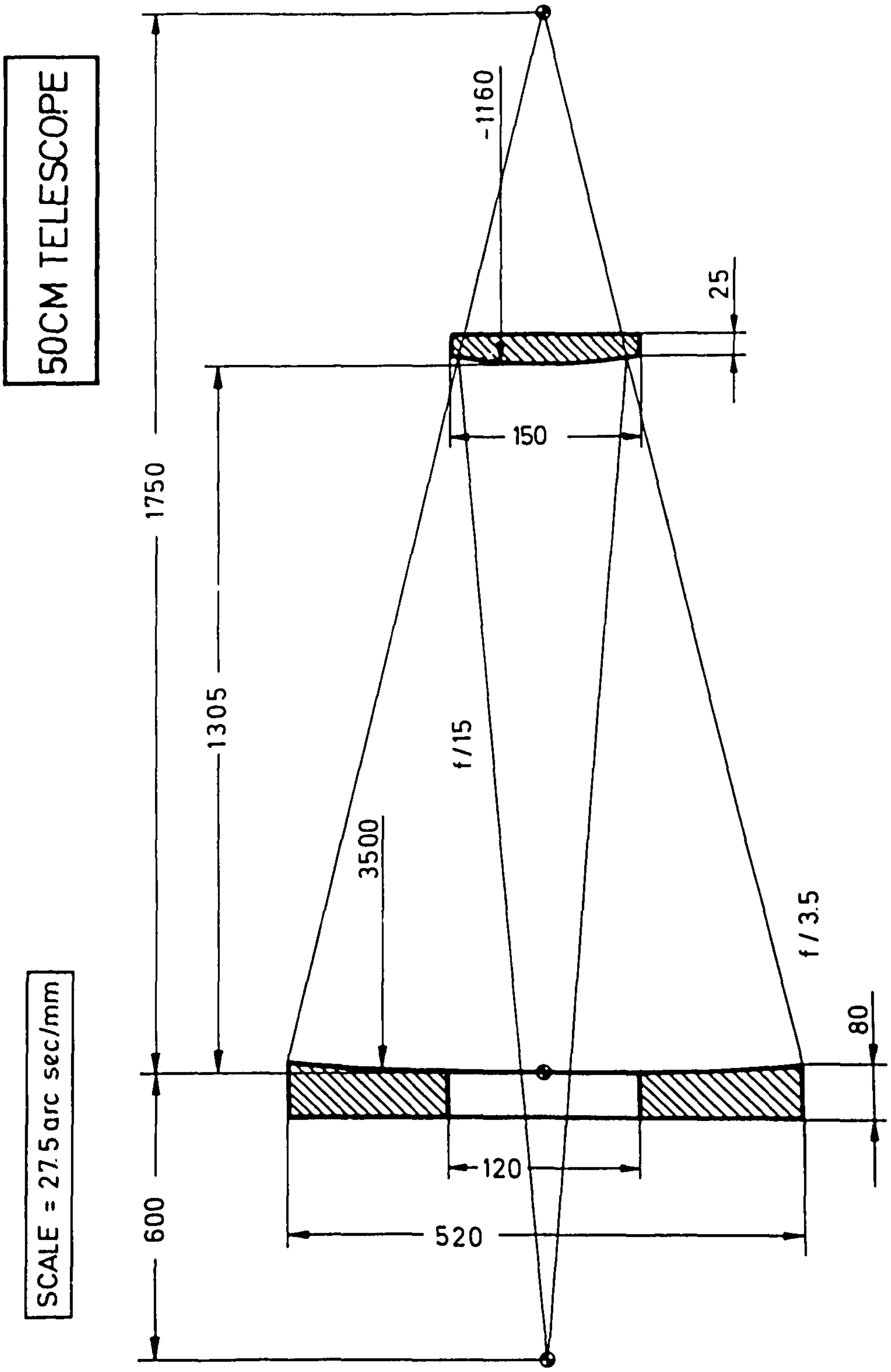


Figure 2.14: 0.5 m ESO telescope

Chapter 3

Instruments

3.1 Introduction and overview

In this chapter, the available instruments at La Silla are described. The aim of this section is to provide enough information about the individual instruments to allow an astronomer to write an observing proposal. Information on how to operate the instruments can be found in the relevant ESO Operating Manuals. At present the following Operating Manuals are available:

Manual #	*Authors*	*Date*	*Title*
2	L. Pasquini, S. D'Odorico,	1989	The ESO Cassegrain Echelle Spectrograph (CASPEC)
4	J. Melnick, H. Dekker, S. D'Odorico	1989	EFOSC (ESO Faint Object Spectrograph and Camera)
5	J. Melnick, H. Dekker, S. D'Odorico	1992	EMMI & SUSI
8	H. Lindgren, A. Gilliotte	1989	The Coudé Echelle Spectrometer, The Coudé Auxiliary Telescope
9	M. Heydari-Malayeri, B. Jarvis, A. Gilliotte	1989	The Boller and Chivens Spectrographs
10	R. Gredel, A.F.M. Moorwood	1991	IRSPEC
11	P. Bouchet	1989	IR Photometers
14	H. Lindgren, F. Gutièrrez W.	1991	The Optical Photometer on the ESO 1m Telescope
15	A. Moneti, A.F.M. Moorwood	1992	IRAC-1. The 2.2 m Infrared Array Camera.
16	H. Lindgren	1992	Photoelectric Photometers
	J. Melnick	1993	EFOSC2: Operating Manual
	A. Moneti	1993	IRAC2: Notes for Observers

Copies of these manuals may be obtained from the Visiting Astronomers Section in Garching or from the astronomy secretary on La Silla. The VA is expected to have read the manual before the observing run. Recent changes introduced to some instruments are generally reported in The Messenger. References to these articles are given in the relevant section of this manual. Some familiarity with IHAP or MIDAS is also required to make optimal use of the instrumentation.

3.2 EFOSC 1

3.2.1 Introduction

EFOSC 1 or the ESO Faint Object Spectrograph and Camera is a low dispersion (4 to 90 nm mm^{-1}) spectrograph for the ESO 3.6 m telescope. It is a "focal reducer" type instrument and is mounted at the Cassegrain focus. It also offers the possibility of direct imaging. In both the direct imaging and the spectroscopic mode the detector used is a Tek CCD with 512 × 512 pixels^2 of 27 μm^2 giving an imaging field size of 5.'2 × 5.'2.

The optics design for both modes is shown in Fig. 3.1 and a schematic of the overall instrument is shown in Fig. 3.2. The light from the f/8 Cassegrain focus of the 3.6 m telescope, after passing through an aperture wheel, is collimated by 2 lens groups producing an image of the telescope primary just in front of the camera. In the parallel beam area there are a filter wheel and a grism wheel. The light then passes to the camera consisting of 3 lens groups, the aspheric camera field lens also acting as the CCD cryostat window. The camera has a focal ratio of f/2.5 giving a projected pixel size of 0.''61. The overall efficiency curve of the EFOSC 1 optics is shown in Fig. 3.3.

3.2.2 Standard aperture plates

The aperture wheel holds up to 11 standard (see Table 3.1) or special (multi-hole) aperture plates; one position must be free for direct imaging. A special movable slit can also be mounted on this wheel. Movable slits of various widths are available but only one can be mounted at any given time. This is a time consuming operation which cannot be done during the night. The position of the movable slit can be adjusted by ±10 mm corresponding to a wavelength shift ±378 D mm where D is the grism dispersion as given in Table 3.2.

Table 3.1: EFOSC 1: standard apertures

Fixed slits (3.9' long) and movable slits (3.1' long) of

0.5 0.75 1. 1.5 2. 2.5 3. 5. 10 arcsec width.

Echelle slits: 9'' long, various widths.

Polarimetry slits: 18'', various widths.

Coronograph mask: opaque spots on a glass plate, various diameters.

Special MOS aperture plates: made to specification.

3.2.3 Filter wheels

The instrument is equipped with a filter wheel with 12 positions. Note that all the filters must have imaging quality over the full 60 mm used. This is an important consideration when bringing your own filters (see ESO Operating Manual # 4 for a detailed specification). Up to 11 filters can be mounted in the filter wheel, always leaving one free position. All filters have a diameter of 60 mm. ESO filters are listed in the ESO filter list (see Chapter 4).

3.2.4 Grisms

The grism wheel holds up to 8 grisms providing different dispersions and central wavelengths. Three positions are reserved for Hartmann screens and a focal analyzer used for focusing. The grisms available are listed in Table 3.2. An echelle grating with a resolving power of ~2000 can also be used with a blue or a red cross-disperser mounted in the filter wheel. A coronograph pupil mask must be mounted in the grism or filter wheel when the coronograph mask is used in the aperture wheel.

Table 3.2: EFOSC 1 grisms

Grism	Dispersion (nm mm^{-1})	Range (nm)	Wavelength bin (nm $pixel^{-1}$) (*)
Blue 1000	85	360–1100	2.3
Red 1000	92	550–1100	2.5
UV 300	21	352–547	0.63
Blue 300	23	364–686	0.63
Red 300	27	594–977	0.75
Blue 150	12	374–545	0.33
Orange 150	13	464–595	0.33
Red 150	12	687–856	0.33
Echelle + blue cross-disperser	3.2–6.3	390–730	0.11 – 0.20
Echelle + red cross-disperser	4.6–8.3	520–910	0.14 – 0.25

(*)These values are based on the Tek CCD with 27 μm pixels.

3.2.5 Detector

The detector presently used is a Tektronix thinned, back illuminated CCD (ESO #26) with 512 × 512 pixels of 27 μm. This chip typically has 10 e^- readout noise and a peak quantum efficiency of 82%. For details, see Chapter 4 and the ESO CCD catalogue.

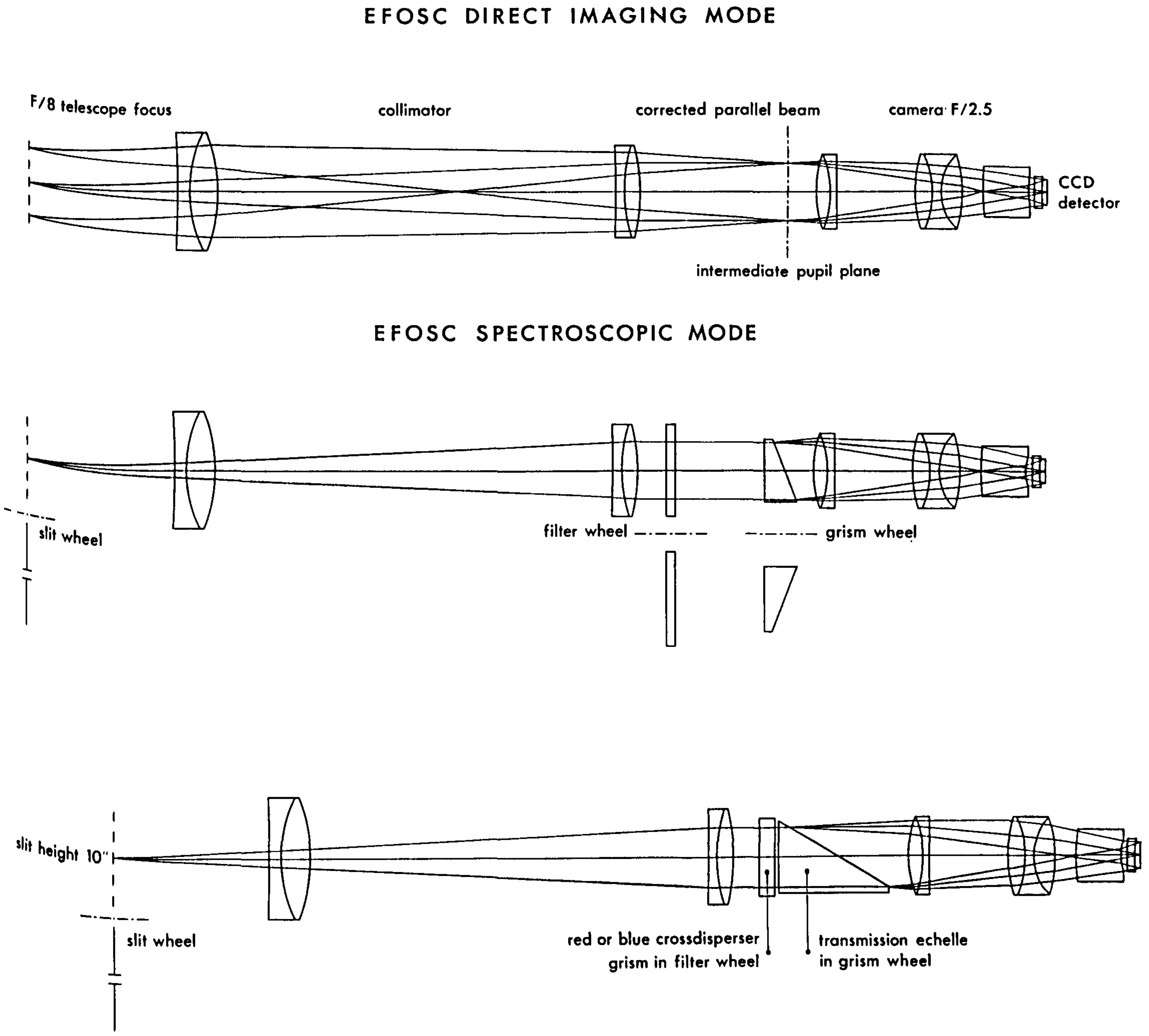


Figure 3.1: EFOSC 1: optical layout

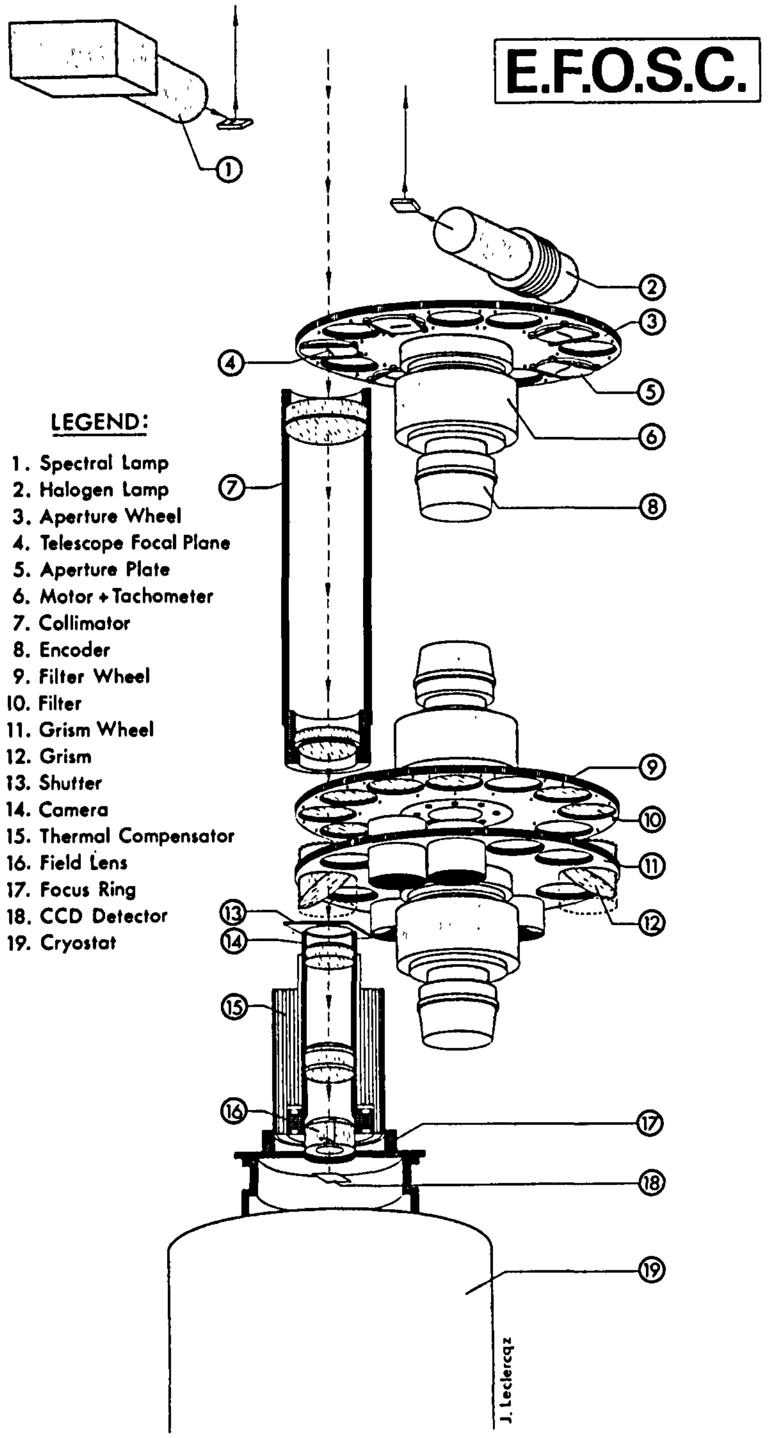


Figure 3.2: EFOSC 1: schematic diagram of the instrument

3.2.6 Pointing and guiding

Pointing in the spectroscopic mode is done by taking a short CCD exposure and running an IHAP batch to calculate the offsets needed to bring the object onto the slit. With an exposure of a few minutes, it is possible to reach 23^{rd} magnitude which is approximately the present limit for spectroscopy.

Guiding in imaging and spectroscopic modes is done on an offset star with the autoguider.

3.2.7 Operating modes

EFOSC is a versatile instrument and can be used in several modes, as follows.

1. **Spectroscopy.** Long slits are available (see Table 3.1) to do spectroscopy with the grisms listed in Table 3.2.
2. **Direct imaging.** With any filter mounted, direct images are taken with a field of $5\overset{\prime}{.}2 \times 5\overset{\prime}{.}2$.
3. **Multi-object spectroscopy (MOS).** A direct image has to be taken from which a starplate can be made using a miniature punching machine (PUMA). The starplate is mounted in the aperture wheel and the field acquired. Up to about 20 spectra can be taken simultaneously in this way.
4. **Spectropolarimetry.** By mounting the 20″ Wollaston prism in the filter wheel, spectropolarimetry can be done. Two images need to be taken with an instrument rotation of 45° between them. A rotating $\lambda/2$ plate conversion is being prepared.
5. **Imaging polarimetry.** By mounting a special mask with strips in the aperture wheel, the 20″ Wollaston prism in the grism wheel, and with a filter in the filter wheel, image strips 20″ wide in orthogonal polarization are taken. Moving the telescope by 20″ then gives the other set of 20″ strips to form a complete image. This procedure must be repeated at a rotated (45°) instrument position to recover all polarimetric information (degree and angle of polarization). With the rotating $\lambda/2$ plate this will no longer be necessary.
6. **Coronography.** By mounting a special plate in the aperture wheel and a pupil stop in the filter wheel, coronograph images (with central obstructions of varying diameter) can be taken through any filter. Faint nebulosity around bright objects would be a typical application here.

3.2.8 Image quality

This is characterized by the diameter which encircles 80% of the energy. In white light (350 nm to 1 μm) imaging, the image quality in the central 10 mm of the field is better than $0\overset{\prime\prime}{.}3$. In the corners the quality is about $0\overset{\prime\prime}{.}5$. A slight disadvantage of this type of

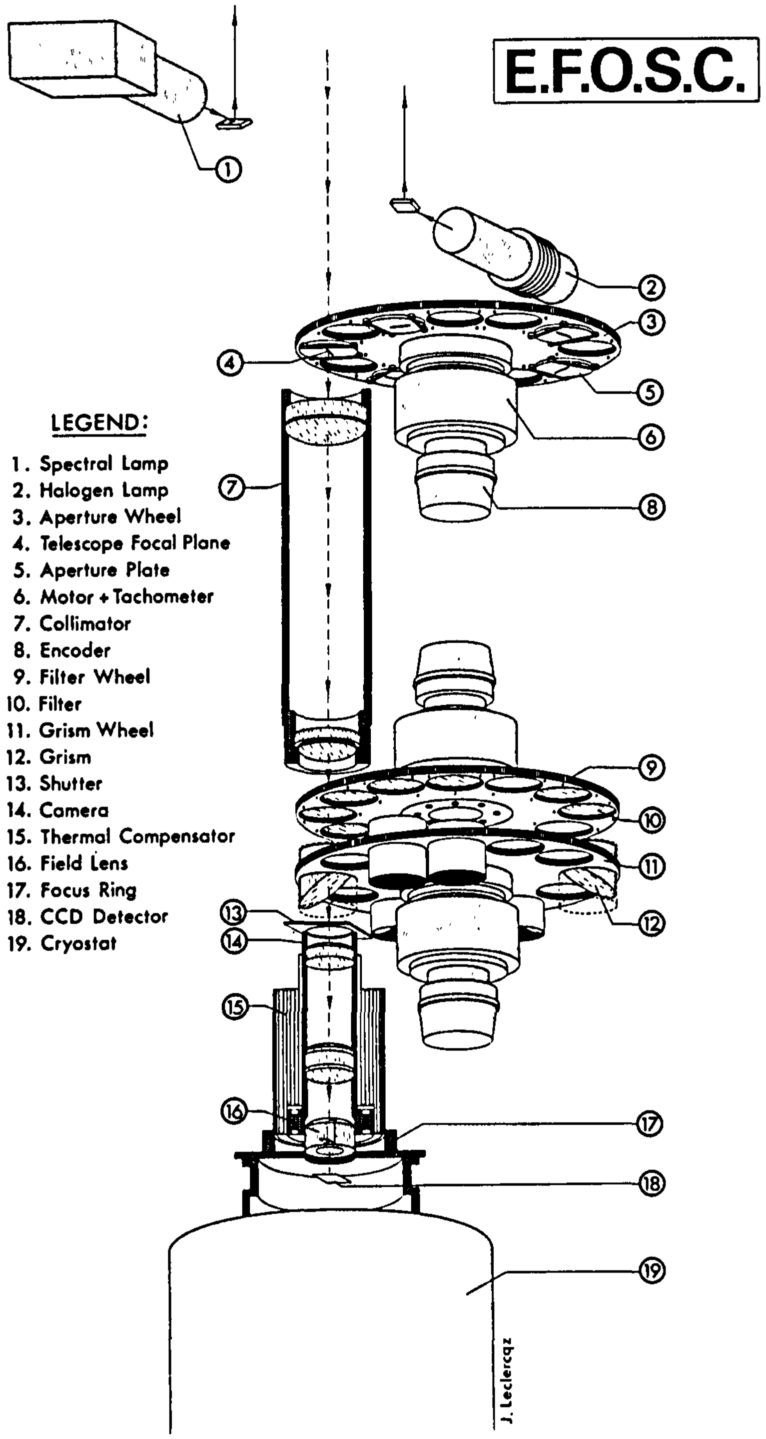


Figure 3.2: EFOSC 1: schematic diagram of the instrument

3.2.6 Pointing and guiding

Pointing in the spectroscopic mode is done by taking a short CCD exposure and running an IHAP batch to calculate the offsets needed to bring the object onto the slit. With an exposure of a few minutes, it is possible to reach 23rd magnitude which is approximately the present limit for spectroscopy.

Guiding in imaging and spectroscopic modes is done on an offset star with the autoguider.

3.2.7 Operating modes

EFOSC is a versatile instrument and can be used in several modes, as follows.

1. **Spectroscopy.** Long slits are available (see Table 3.1) to do spectroscopy with the grisms listed in Table 3.2.
2. **Direct imaging.** With any filter mounted, direct images are taken with a field of $5'.2 \times 5'.2$.
3. **Multi-object spectroscopy (MOS).** A direct image has to be taken from which a starplate can be made using a miniature punching machine (PUMA). The starplate is mounted in the aperture wheel and the field acquired. Up to about 20 spectra can be taken simultaneously in this way.
4. **Spectropolarimetry.** By mounting the $20''$ Wollaston prism in the filter wheel, spectropolarimetry can be done. Two images need to be taken with an instrument rotation of 45° between them. A rotating $\lambda/2$ plate conversion is being prepared.
5. **Imaging polarimetry.** By mounting a special mask with strips in the aperture wheel, the $20''$ Wollaston prism in the grism wheel, and with a filter in the filter wheel, image strips $20''$ wide in orthogonal polarization are taken. Moving the telescope by $20''$ then gives the other set of $20''$ strips to form a complete image. This procedure must be repeated at a rotated (45°) instrument position to recover all polarimetric information (degree and angle of polarization). With the rotating $\lambda/2$ plate this will no longer be necessary.
6. **Coronography.** By mounting a special plate in the aperture wheel and a pupil stop in the filter wheel, coronograph images (with central obstructions of varying diameter) can be taken through any filter. Faint nebulosity around bright objects would be a typical application here.

3.2.8 Image quality

This is characterized by the diameter which encircles 80% of the energy. In white light (350 nm to 1 μm) imaging, the image quality in the central 10 mm of the field is better than $0''.3$. In the corners the quality is about $0''.5$. A slight disadvantage of this type of optical design is the so called sky concentration. It appears as a diffuse area 1 to 2% above the background in the centre of the image. It is due to light which is reflected back by the chip into the camera and returned by some optical surface. The largest contributions come from the field lens and experience indicates that flat-fielding will correct this effect.

3.2.9 Data acquisition and reduction

The instrument is under the control of an HP 1000 computer. The software consists of three main programs. A user interface program with softkey menus can be chosen and forms filled in; the instrument control program takes care of the CAMAC communication and the CCD program sends control commands to the detector and reads out and stores the images on disk. The user interface also provides access to the IHAP image processing program for data reduction. It is expected that MIDAS will become available for on-line data reduction during 1993.

3.2.10 Exposure times and limiting magnitudes

Integrated counts for a star of 15^{th} mag in a one minute exposure near zenith gave:

U: 18 kADU/min B: 190 kADU/min V: 410 kADU/min R: 466 kADU/min

The conversion factor on CCD # 26 was 3.9 e^- per ADU. The counts in V and R are based on two stars that were measured on two different frames. B counts are based on two stars measured on three different frames, and U counts are based on two stars measured on one frame. Seeing was 1.3″ FWHM.

3.2.11 Calibration

Up to four calibration lamps are provided in order to flat field and provide wavelength calibration. A reflecting screen is mounted on the top of the telescope sky baffle. Dimensions and central obscuration match those of the primary mirror and it can be inserted with a handset in the control room in the optical path to reflect the light from the calibration lamps.

For flat fielding there are internal quartz lamps which reflect light off the closed sky baffle cover as described above.

Spectral calibration lamps (He, Ar, Ne, Cs) can be used in the same way.

For imaging, flat fielding can be done with internal lamps, illuminated dome or sky light. See Chapter 4 for more information about flat fielding CCD data.

References

- Dekker, H., D'Odorico, S., 1984, The Messenger **37**, 7
- Buzzoni, B. et al., 1984, The Messenger **38**, 9

- Dekker, H. et al., 1988, *A&A* **189**, 353
- Melnick, J., Dekker, H., D'Odorico, S., 1989, ESO Operating Manual # 4

3.3 EFOSC 2

3.3.1 Introduction

EFOSC2 is a copy of EFOSC1 originally used during the commissioning phase of the NTT and now permanently installed at the 2.2 m telescope. The optics of EFOSC2 are an improvement over these of EFOSC1 in that a) the UV response is enhanced and b) the sky concentration has been reduced.

3.3.2 Grisms

There are 10 grisms presently available for EFOSC2. The characteristics of these units are presented in Table 3.3.

There are in addition 2 prisms which, because they do not produce zero-th order images are useful for slitless spectroscopy. The characteristics of these prisms are shown in Table 3.3.

The overall transmission curves of the optics of the two EFOSC instruments are presented in figure 3.3.

Coronography and Polarimetry options are available with EFOSC2, but not the MOS option which is only available with EFOSC1.

Table 3.3 lists the grisms presently available on EFOSC2. Efficiency curves for these grisms can be found in the "EFOSC2 Operating Manual" available from the Visiting Astronomers Section in Garching.

3.3.3 Slits

Fixed and movable slits of widths 0.7", 1", 1.5", 2", 5", and 10" are available for EFOSC2. As for EFOSC1 only one movable slit can be mounted at any given time and this operation can only be done during day time. The wavelength shift corresponding to the movable slit maximum displacement of ±10 mm corresponds to ± 860 × D nm where D is the grism dispersion as given in Table 3.3.

Both the fixed and the movable EFOSC2 slits are 5.7' long.

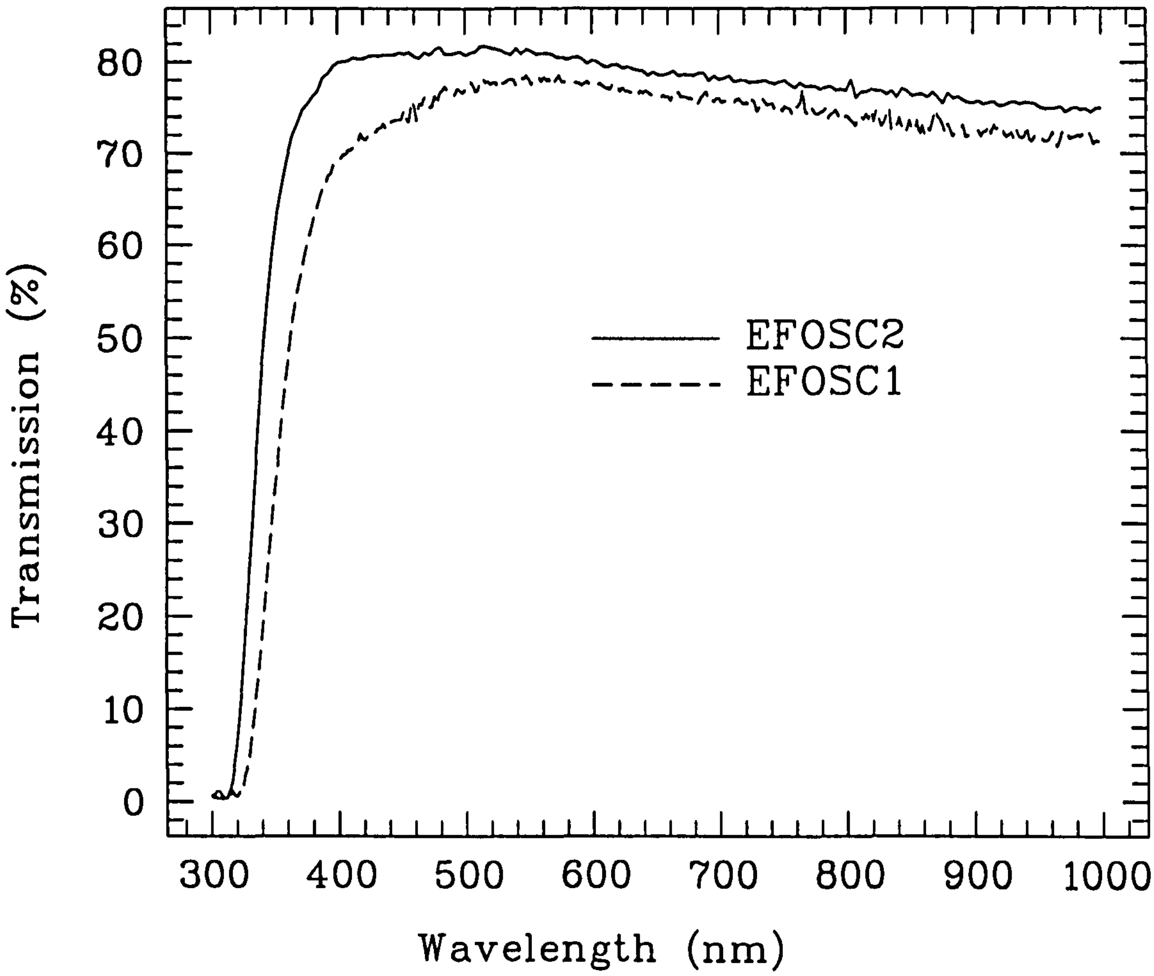


Figure 3.3: Efficiency curves of the optics of EFOSC 1 and EFOSC 2. Notice the improvement in UV transmission of the EFOSC 2 optics with respect to EFOSC 1.

Table 3.3: EFOSC 2 grisms

Grism #	l/mm	blaze (nm)	Wavelength range*	Dispersion* (nm/pix*)
1	100	450	340 – 920	0.84
2	100	670	540 – 1050	0.84
3	400	390	352 – 547	0.19
4	360	470	465 – 680	0.22
5	300	670	580 – 840	0.25
6	300	500	460 – 720	0.27
7	600	380	358 – 484	0.12
8	600	530	464 – 595	0.13
9	600	650	587.5 – 702	0.11
10	600	650	660 – 782	0.12
prism #1	–	–	350 – 550	2.7 nm/pix @ 525 nm 5.0 nm/pix @ 610 nm
prism #2	–	–	500 – 800	2.7 nm/pix @ 350 nm 5.1 nm/pix @ 525 nm

*For THX 1024 CCD with 19μm pixels

3.3.4 Filters

Table 3.4 lists the filters of the EFOSC2 basic set. Hβ line and continuum filters and Washington C filters are on order. All filters are 60 mm diameter and image quality is described in the previous section.

Table 3.4: EFOSC2 filters: basic set

#631 U	#616 gun g	689 CoII
#583 B	#617 gun r	694 Hα
#584 V	#618 gun i	698 Hα redsh.
#585 R	#619 gun z	702 [SII]

3.3.5 Coronograph

As EFOSC1 coronography on EFOSC2 is possible using a focal plane mask and a light stop. Use of the light stop reduces significantly the scattered light and is therefore strongly recommended. The coronograph mask has 6 spots of diameters 2.5", 3.3", 5.0", 6.6", 10.0", and 13.3" distributed in a rectangular array, separated by 1'.

3.3.6 Polarimetry

The Wollaston prisms from EFOSC1 can be mounted on EFOSC2. The corresponding beam separations are 17.6” and 35”. Special masks are available for imaging polarimetry.

3.3.7 Detector

At present, EFOSC 2 is equipped with a Thomson THX31156 coated CCD (ESO# 19), with 1024×1024 pixels^2 of $19\mu m^2$ each projecting $0''.34$ onto the sky. The FOV is $5'.7 \times 5'.7$.

For details, see Chapter 4 and the ESO CCD catalogue.

3.3.8 Efficiencies:

Tables 3.5 and 3.6 give typical count rates for direct imaging and spectroscopy.

Table 3.5: EFOSC 2 efficiency in spectroscopy mode

Monochromatic Magnitude	e$^-$/sec/Å											
LTT 9239	13.4	12.8	12.4	12.2	12.0	11.9	11.8	11.8	11.7	11.6	11.6	
Grism #	350	400	450	500	550	600	650	700	800	900	1000	(nm)
1	3.5	14	28	55	173	63	58	51	32	6.5	—	
2	—	—	—	0	60	78	84	82	39	14	2	
3	—	—	—	—	—	—	—	—	—	—	—	
4	—	—	0	51	67	62	57	0	—	—	—	
5												
6	—	0	25	53	72	70	67	54	0	—	—	
7	5	13	22	0	—	—	—	—	—	—	—	
8	—	—	—	45	61	—	—	—	—	—	—	
9	—	—	—	—	—	45	51	—	—	—	—	
10												

References

- Melnick, J., 1993, EFOSC2 Operating Manual.

3.4 CASPEC

3.4.1 Introduction

The Cassegrain Echelle Spectrograph (CASPEC) is used at the 3.6 m telescope. The spectrograph is shown schematically in Fig. 3.4. It can be used in various optical configurations, defined by the various possible combinations of two echelle gratings (“standard”:

Table 3.6: *Typical count rates in the UBVRI(z) system*

			count rate ($\times 10^3 e^-$/sec)					
Star	V	B-V	U	B	V	R	I	Z
98-670	11.93	1.36	0.3	10.8	97.2	202	104.6	-
Mark A2	14.54	0.68	0.12	1.6	8.8	14.0	5.6	3.1
98-685	11.95	0.47	1.6	18.8	90.8	113.6	50.4	-
Mark A	13.26	-0.24	2.4	9.4	27.6	29.2	7.6	3.3*

* Notice that Mark A has a faint, extremely red companion

31.6 lines mm^{-1}, blaze angle 63°.4; "alternative":52.65 lines mm^{-1}, blaze angle 63°.5), two cross-disperser gratings ("blue": 300 lines mm^{-1}, blaze wavelength 422 nm, blaze angle 3°.5; "red": 158 lines mm^{-1}, blaze wavelength 800 nm, blaze angle 3°.6), and two cameras ("short": focal length = 291 mm, f/1.46; "long": focal length 560 mm, f/3). A long slit mode is also offered, by replacing the cross-disperser gratings by a flat mirror.

The instrument is controlled via an HP 1000 computer using the usual softkeys at the HP console.

For detailed information about CASPEC, see ESO Operating Manual # 2, Pasquini & Gilliotte (1991, 1993), and Pasquini et al. (1992).

3.4.2 Detector

At present, CASPEC is used with a Tektronix TK512 CCD of 512 × 512 pixels^2 of 27 μm^2 (ESO # 32). A large format CCD may become available with the long camera in 1993. With the short camera, 1 mm on the CCD corresponds to 39″.2 in the direction of the dispersion and to 26″.4 in the direction of the cross-dispersion, at the blaze and at the centre of the chip. With the long camera, the corresponding figures are 20.2"/mm in the dispersion direction and 13.7"/mm perpendicular to it.

3.4.3 Spectral coverage, inter-order space, and resolution

With the short camera, the standard (31.6 lines mm^{-1}) echelle grating and the blue cross-disperser, one CCD frame covers approximately 140 nm. The orders are packed more tightly with a broader wavelength overlap towards the blue. Adequate order overlapping is assured in the red up to 780 nm. With this configuration, the separation between orders becomes small in the blue, as illustrated in Fig. 3.6.

The alternative (52 lines mm^{-1}) echelle grating is recommended for use at $\lambda < 420$ nm or if larger order spacing is needed (longer slit length). The actual order separation for this grating can be obtained at a given wavelength by multiplying the values given in Fig. 3.7 by 1.6. Full spectral coverage is achieved up to $\lambda = 480$ nm, i.e. wavelength overlap between orders is sufficient in the blue only, but lost in the red. In Table 3.7, the recommended upper limits for slit lengths at various wavelengths are given for the 31.6 lines mm^{-1} echelle (with the blue cross-disperser and the short camera). Multiply by 1.6 to obtain the corresponding values for the 52 lines mm^{-1} echelle.

As to the slit width, a trade-off is necessary between maximum light input and resolution. One pixel at the detector corresponds to 149 μm at the focal plane ($1''.06$). There is no gain in using a slit narrower than $2''.12$, which projects onto 2 pixels.

At wavelengths longer than 550 nm, the red cross-disperser should be used for maximum efficiency. With it, the standard echelle and the short camera, a CCD frame covers 280 nm. The order separation is correspondingly smaller than with the blue cross-disperser. The red cross-disperser should therefore not be used below 550 nm. The following additional restrictions should also be noted. If the red and blue ranges are to be observed in the same night the blue cross-disperser should be used as cross-disperser changeovers during the night are not possible. Currently, even staying in the range allowed by the red cross-disperser, it is also impossible to change the central wavelength during the night. Finally, there is no order overlap at wavelengths longer than about 815 nm. By tilting the cross-disperser it is possible to observe any portion of the orders (i.e., not necessarily the central part). This adjustment, however, must be made in the afternoon during the setup procedure.

It is a well known property of an echelle that, as the dispersion increases toward the blue, the resolving power remains approximately constant over the entire spectral range. With the short camera and a 310 μm ($2''.2$) wide slit, the resolving power was estimated to be approximately 18 000 (regardless of the echelle grating and of the cross-disperser used).

An atlas of the thorium spectrum made with CASPEC (using the short camera), which covers the wavelength range 340-900 nm, is available (D'Odorico et al. 1987).

With the long camera, the resolving power and the order separation are 1.92 times larger than with the short camera. However, the portion of the spectrum covered by each order is only 46% of the wavelength ranges shown in the D'Odorico et al. thorium atlas, thus there is no order overlap. Any portion of the orders can still be observed by tilting the cross-disperser. But this adjustment can only be performed during daytime, and it cannot be changed by the observer during the night. Note also that, to take full advantage of the increased resolving power, the slit width must be reduced by the same factor (down to $1''.1$).

3.4.4 Limiting magnitude and sensitivity

The efficiency of both cross dispersers is shown in Fig. 3.5. A calculation of the expected S/N ratio per pixel at 550 nm for stars of different magnitudes has been made for the short camera, blue cross-disperser, and 31 lines mm^{-1} echelle grating. Although intended as a guideline, it has proved to be quite accurate. Using a standard star, the overall

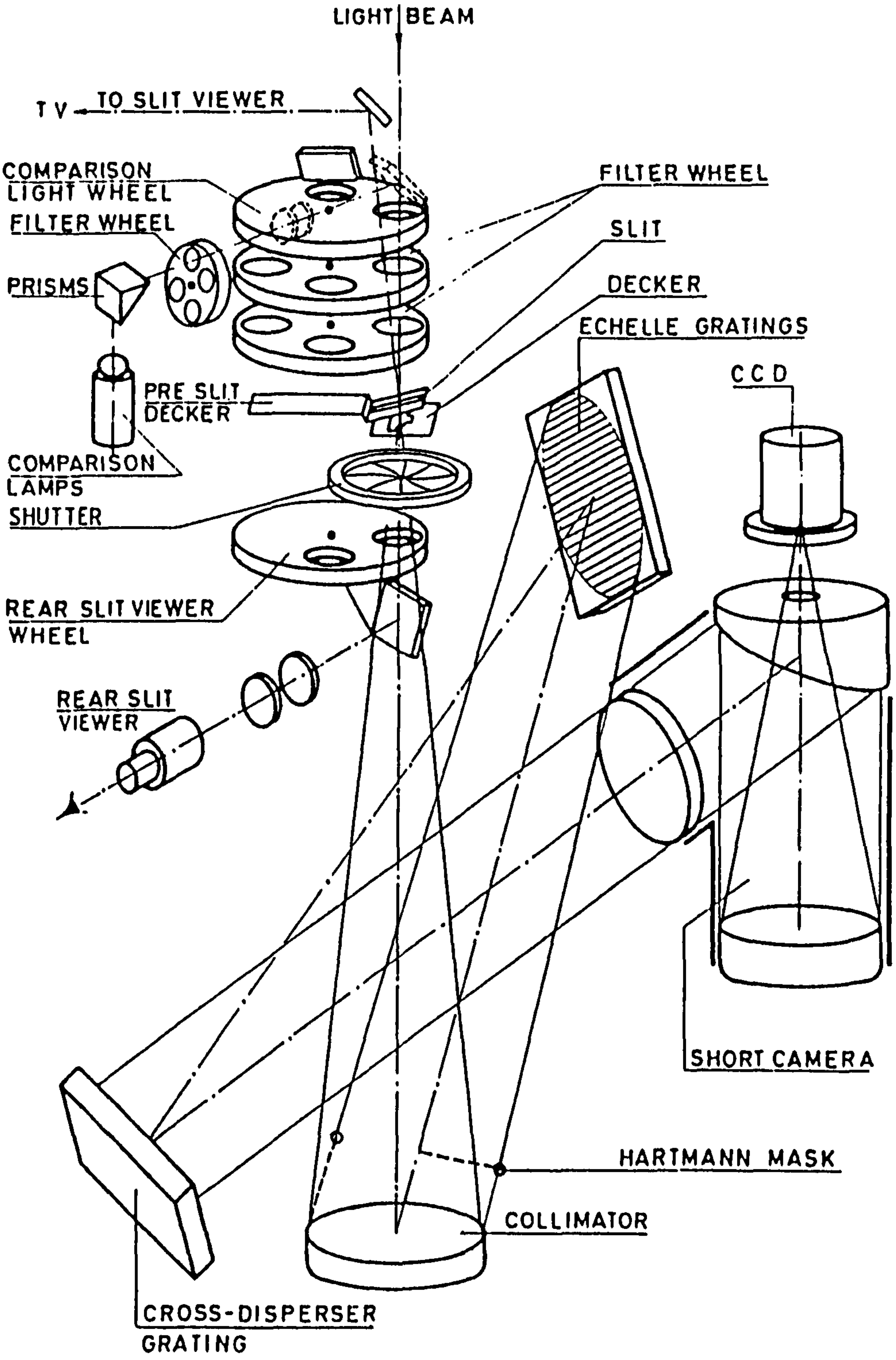


Figure 3.4: CASPEC: schematic of instrument

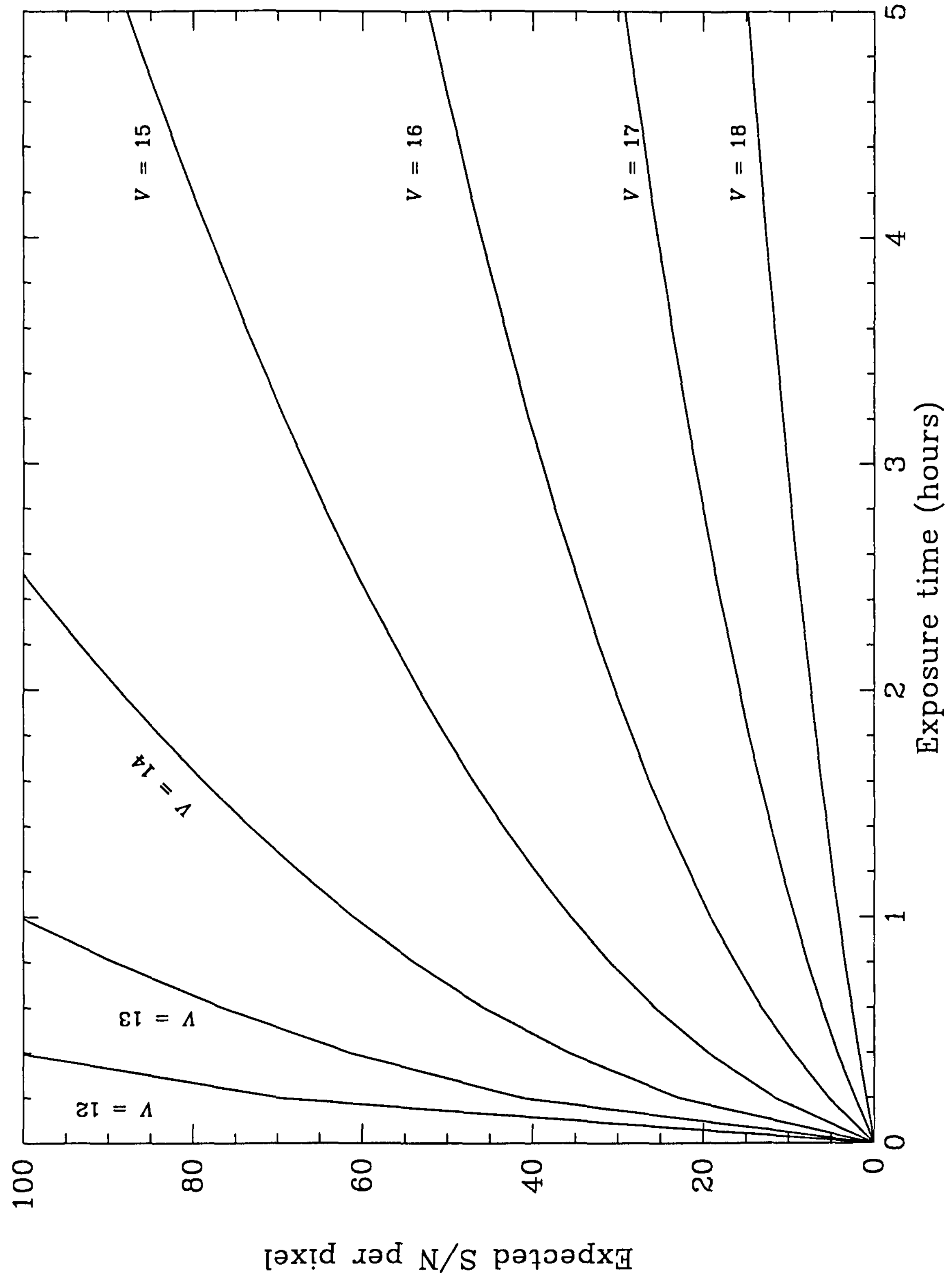


Figure 3.5: CASPEC: cross-dispersers efficiency

efficiency was determined, from which the limiting magnitudes shown in Fig. 3.6 were then computed. The assumptions were: spectrum spread over 5 pixels in the cross-dispersion direction, reciprocal dispersion of 0.014 nm pixel^{-1}, and the characteristics of CCD # 32. In a 1 hour exposure, the CCD readout noise dominates for objects fainter than 16.5 mag.

Table 3.7: CASPEC: recommended slit lengths with 31.6 lines mm^{-1} echelle and blue cross-disperser

λ central (nm)	380	450	550	650	750
Max. slit length (mm)	280	420	700	1540	1960
Max. slit length (arcsec)	2	3	5	11	14

3.4.5 Polarization analyzer

CASPEC has a polarization (or Zeeman) analyzer, installed after the slit, which can be called in from the instrument control programme. The light first goes through an achromatic retarder, either $\lambda/4$ or $\lambda/2$, and then through an integrated unit (the analyzer proper) comprising a Wollaston prism followed by an achromatic $\lambda/4$ plate. The Wollaston prism splits the incoming light into two beams of orthogonal linear polarizations, which are converted into two beams of opposite circular polarizations by the $\lambda/4$ plate, so that they are transmitted with the same efficiency by the following optical elements of the spectrograph. By selecting the $\lambda/4$ or the $\lambda/2$ plates in front of these integrated elements, one can use the analyzer to observe either circularly or linearly incoming polarized light. Spectra in all 4 Stokes parameters can in that way be recorded in 3 exposures (one switches between parameters Q and U by rotating the whole CASPEC by 45°). The system includes compensation for the change of focus, so that observations with and without the polarization analyzer can be performed in a single night.

The achromatism of the retarders is restricted to the wavelength range 460-680 nm, so that the analyzer can only be used within this range. Note however that with the 31 lines mm^{-1} echelle grating, the split orders will overlap shorter of about 570 nm. By using the 52 lines mm^{-1} grating, it is possible to observe with the polarization analyzer down to 460 nm. With the short camera, the limiting magnitude for a well-exposed continuum spectrum is about 13.

3.4.6 Long slit mode

In this mode, the cross-disperser is replaced by a flat mirror and a spectral region is isolated by means of an interference filter. By choosing the filter passband to be narrower than an echelle order, a long slit can be used without order overlapping. The maximum slit length is 2 cm or 144″. This is a useful mode for extended objects in which one or a few lines have to be obtained. Note that the filters can be selected from the ESO filter list. They need to have a diameter of 25 mm and may not be thicker than 10 mm.

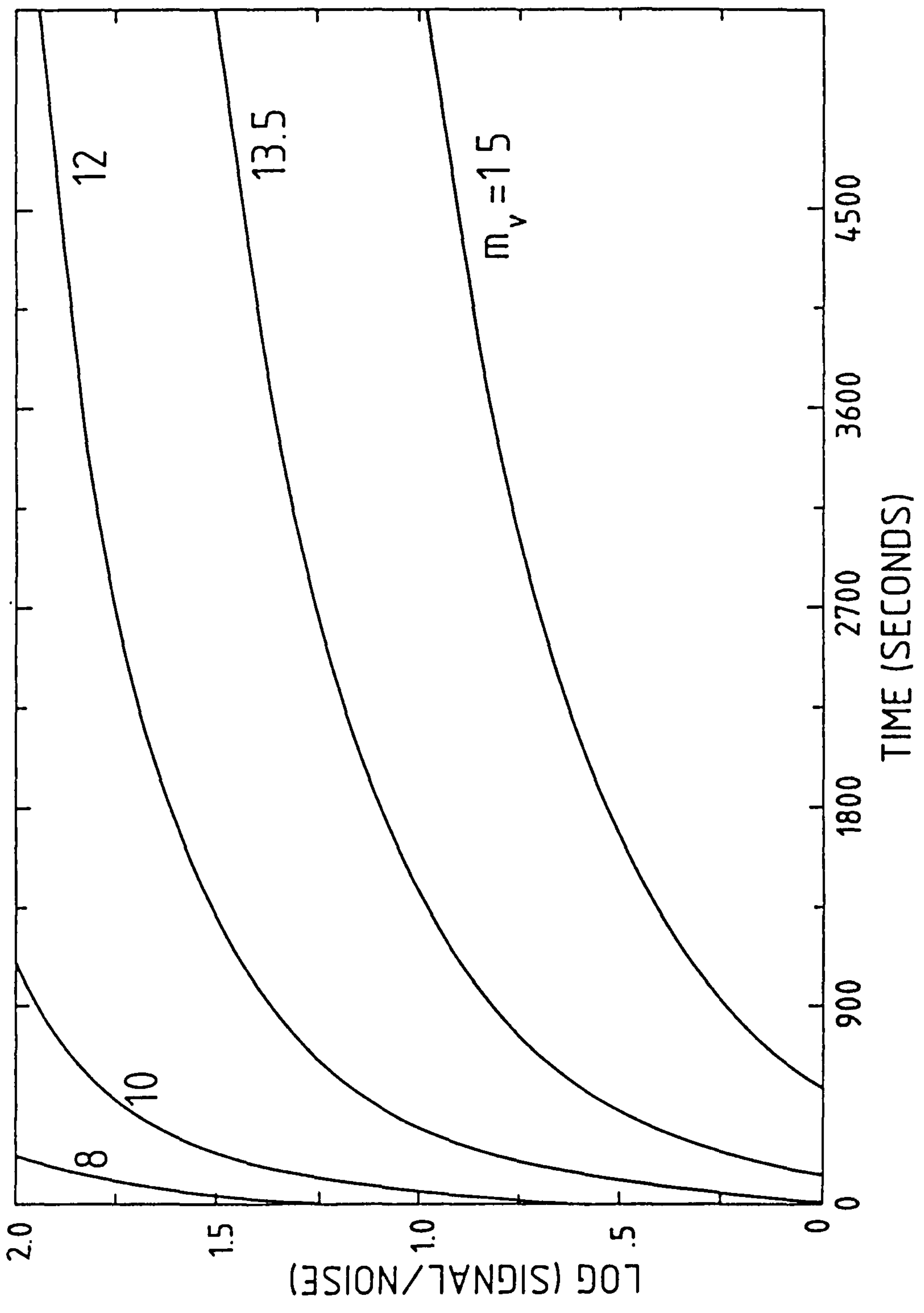


Figure 3.6: CASPEC: expected S/N per pixel at 550 nm as a function of exposure time.

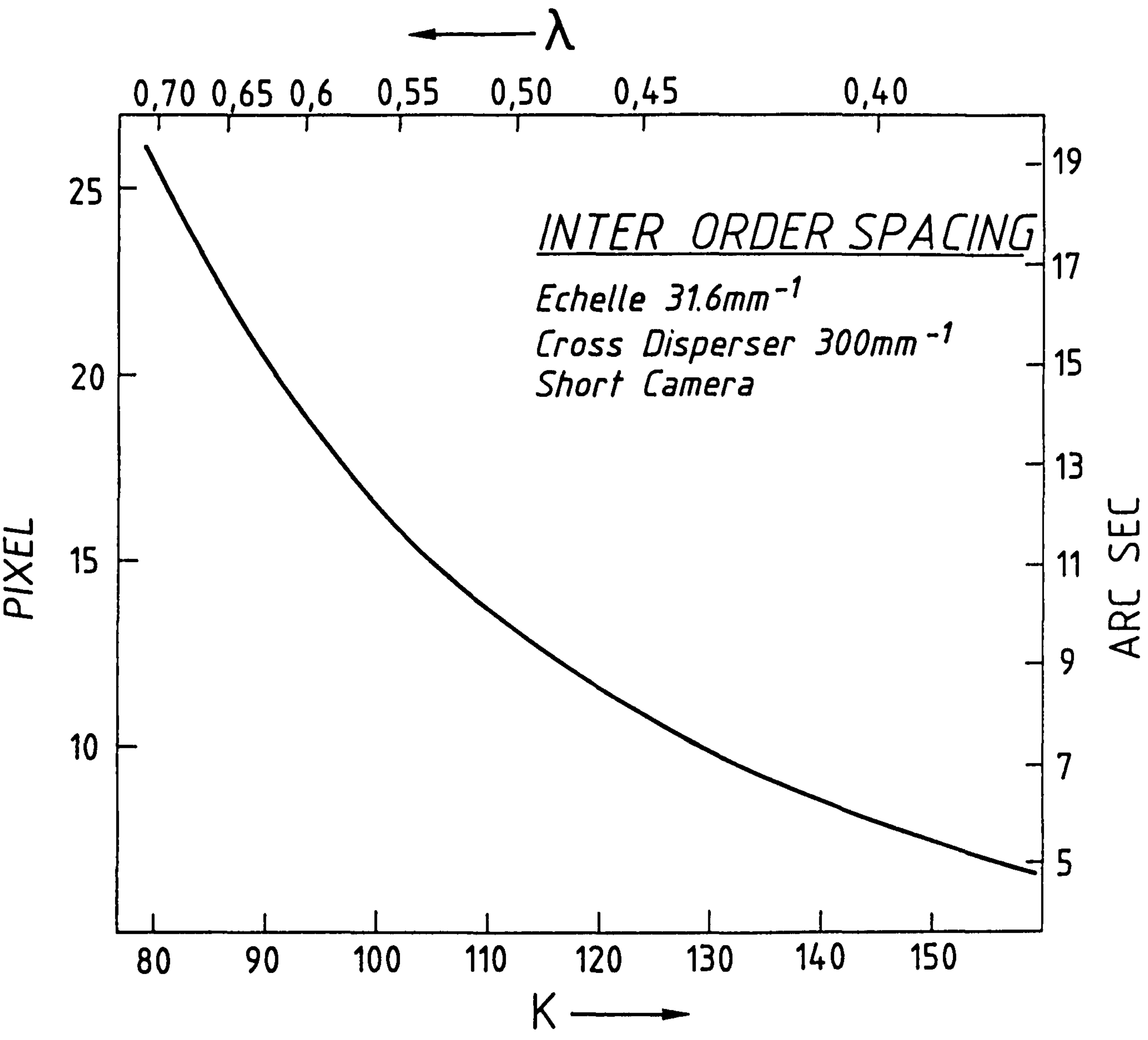


Figure 3.7: Order separation in CASPEC

3.4.7 Calibration and reduction

A minimum set of calibration exposures which should accompany the observations consists of a set of bias/dark exposures, a wavelength calibration exposure (thorium lamp), and a flat field exposure. A standard star should be observed to determine the instrumental response and/or to flux calibrate the spectra.

The thorium lamp is used to obtain wavelength calibration. Because of possible flexure problems, it is best to take the calibration spectra at the same telescope position as the science exposures. For details of attainable velocity accuracy see D'Odorico and Ponz (1984).

Flat-fielding is done using an incandescent lamp in the spectrograph. Neutral density and colour filters are available for calibration exposures. Exposure times should be obtained by experimenting in the afternoon before observing.

References

- D'Odorico et al., 1987, *An atlas of the thorium-argon spectrum for the ESO Echelle Spectrograph*, ESO
- D'Odorico et al., 1983, The Messenger **33**
- D'Odorico, S. and Ponz, D., 1984, The Messenger **37**
- Pasquini, L., and D'Odorico, 1989, ESO Operating Manual # 2
- Pasquini, L., and Gilliotte, A., 1991, The Messenger **65**, 50
- Pasquini, L., Rupprecht, G., Gilliotte, A., and Lizon, J.-L., 1992, The Messenger **67**, 50
- Pasquini, L., and Gilliotte, A., 1993, The Messenger **71**, 54

3.5 TIMMI

TIMMI (Thermal Infrared MultiMode Instrument is a thermal IR camera which allows for direct imaging at 5.10 and 17 μm. It is optimized for 10 μm observations. It is expected that the instrument will offer in the future long slit (~ 25 arcsec) spectroscopy with a resolving power of about 300 (1 pixel).

A description of the system and a typical image may be found in Kaüfl et al. (1992, The Messenger, 70, p. 67).

For optimum cancellation of the strong thermal background radiation TIMMI is operated in chopping (and generally, nodding) modes. It is interfaced to the telescope with the standard infrared f/35 adaptor (see 'Infrared Photometers, ESO Operating Manual No. 11, P. Bouchet), and it may be used in parallel together with the Bolometer or the InSb-photometers.

3.5.1 Technical characteristics

Detector

The array developed at the LIR is an hybrid device consisting of a gallium doped silicon photoconductor hybridized by indium bumps to a 64 × 64 Direct Voltage Readout array made of silicon. A particularity of the array is its large storage capacity.

Table 3.8: LIR Array

Format:	64 × 64
Photoconductor material:	Si:Ga
Wavelength range:	5-17.8 μm
Filling factor:	$> 80\%$
Quantum efficiency:	$\sim 25\%$
Readout system:	Direct Voltage Readout
Well capacity:	$3 \times 10^{-2} e^-$ (l=1.2Pf)
Noise at dark:	270 Volts (2900 e^-)
Frame rate used:	≥ 7.3 ms
Cosmetic quality:	excellent (1 bad pixel)
Dark current:	negligible ($<10^5$ e^-/s)
Diaphoty, crosstalk:	negligible (< a few %)

The 32 outputs of the array are multiplexed into 2 analog-to-digital 14 bit converted cards. The electronics works at a rate of $\geq$1.8 ps per pixel.

The acquisition system is based on a VME OS9 system which provides for the generation of the clock signals required for the detector read-out, the control of the chopping and nodding, processing of the raw data (the maximum detector read speed is ms for 4096 pixels), quicklook on a colour monitor, control of the motorized functions, and an user interface.

The detector array is integrated into a liquid Helium/solid nitrogen cryostat which keeps the detector at ≈ 10K, the filters at ≈ 60K, and the optics at 60-80K. A germanium entrance window serves also as a field lens.

The autonomy of operation is longer than 24 hours, which ensures stable operating conditions for the observer.

Optics

Three lenses (antireflection coated germanium) are used: a field lens (see above), a collimator followed by a pupil stop, and a set of objective lenses located on a wheel. The focal plane of the telescope lies inside of the dewar. The lens wheel holds three lenses to be used in the 5 and 10 μm window (leading to scales of 0.3, 0.45 and 0.6"/pixel), and a specialized lens (from CdTe) for 17μm observations (0.3"/pixel). The image quality is close to diffraction limited. The filter wheel will also hold grisms to be used for the future spectroscopic option (for this option, a slit can be inserted in the focal plane, 2 cm behind the field lens). See Table 3.9 for the available filters.

Table 3.9: TIMMI filters

Name	$\lambda_o(\mu m)$	$\Delta\lambda$ (μm)
M	4.71	0.63
N	10.10	5.10
N1	8.39	0.96
N2	9.78	1.29
N3	12.56	1.41
ArIII	8.99	0.19
SIV	10.52	0.23
NeII	12.78	0.25
Q	12.15	1.50
—	11.65	2.70*
SiO	9.70	0.49
SiC	11.30	0.57
—	10.69	0.43
—	8.60	0.40
—	7.70	0.35

* Note that this filter creates a 2% ghost.

3.5.2 Sensitivity and limiting magnitudes

Generally, the sensitivities do not depend strongly on the scale chosen. It should be noted that the sensitivities have a 'snap-shot' character since they depend strongly on the atmospheric conditions. In Table 3.10 the integration time given is the actually elapsed time at the telescope, and can be taken to estimate integration times required for the respective observational program.

Table 3.10: TIMMI sensitivity for point sources

Scale ("/pixel)	Filter	limiting magnitude (S/N= 10 in 1 hour)
0.45	N	6.3
0.30	N	7.2 (S/N= 10 in 4 hours)
0.30	10.3-13μm	5.0
0.30	11.06-11.63μm	4.4
0.30	16.5-17.8μm	-1

In narrow band imaging, (e.g. SIV filter) a line integrated flux density of $\approx 10^{-16}$

$Wm^{-2}arcsec^{-1}$ can be detected reasonably well in 1 hr. At N2, with the 0.45 arcsec/pixel scale, the NEFD per pixel is 100mJy $min^{-1/2}$ at the 1σ level. (i.e.: An extended homogeneous source with a surface brightness of 104 $(0.45)^2$ mJy $arcsec^{-1}$ can be detected at the 1σ level in one minute). By degrading the resolution to 1 arcsec, the NEFD=20 mJy $arcsec^{-2}$.

3.5.3 User interface and data acquisition

TIMMI is operated from a normal terminal by filling in forms. In that way all important parameters are set (on chip integration, chopping frequency and amplitude, detector bias, selection of lens and filters, etc.) The front end provides for some basic information such as a quick look colour display of the video data and the cumulated data of a series of integrations. Some statistical values are also calculated on line.

The TIMMI-front end is connected via Ethernet to a Unix-host, where all data are stored. For a better quick-look and limited analysis, MIDAS can be used on that host. A laser printer is available for hard copies. Data are stored in MIDAS bdf format and can be connected to FITS format. Cumulated images of the observations are calculated quasi on line.

Other References

- Lagage et al., 1993: CEA Saclay, SAP 1993, to appear in the proceedings of the SPIE Conference 'Infrared Detectors and Instrumentation', Orlando (USA), 14-16 April 1993, Vol. 1946.

3.6 OPTOPUS

3.6.1 Introduction

The optical fibre system OPTOPUS enables the conventional use of the Boller and Chivens spectrograph to be extended to multi object spectroscopy. OPTOPUS allows the spectra from up to 50 objects located within the 33′ diameter field of the Cassegrain focal plane of the 3.6 m telescope to be simultaneously recorded. The main parameters of OPTOPUS are summarized in Table 3.11.

The fibre component of the instrument consists of 50 separately cabled optical fibres which pick up the light from objects in the focal plane and bring it to a "common" slit. The fibre input ends are located in the focal plane by means of precision connectors plugged into drilled "starplates".

The conventional spectrograph entrance slit is replaced by the "fibre slit". This unit is composed of the 50 fibre output ends arranged in a straight polished row. Each fibre output provides a uniform circular spot of light giving a set of parallel independent spectra at the CCD detector.

Table 3.11: Summary of physical constants and constraints for OPTOPUS starplates

Field scale:	7.12 arcsec mm^{-1}
Maximum field:	33 arcmin (274 mm) diameter circular field
Fibre size on sky:	2.3 arcsec
Maximum number on objects:	50
Number of guidestars:	5
Faintest guidestar magnitude:	15
Maximum magnitude difference for guidestars:	2.5
Minimum object-object separation:	25 arcsec (3.4 mm)
Minimum guidestar-object separation:	64 arcsec (9 mm)

OPTOPUS is equipped with its own acquisition and guiding system. Neither the conventional spectrograph slitviewer, nor the Cassegrain guide probe can be used with OPTOPUS. Guiding is done using fiducial guidestars whose images are picked up by means of five coherent fibre bundles and fed to a TV camera.

3.6.2 Starplates

The OPTOPUS starplates (320 mm diameter, 6 mm thick) are prepared in advance of observations at La Silla. The observer must provide a list of accurate (error $< 1''$) (α, δ) positions. The astrometric facilities in Garching may be used for that purpose. The reduced object position coordinates are treated by a conversion software package which produces a set of X, Y drilling coordinates. These drilling coordinates are fed to a programmable milling machine. The machine programs are designed to include compensation for the field curvature of the telescope focal plane (by hole angle and depth adjustment), and for atmospheric differential refraction.

3.6.3 Optical fibres

The fibres are made of silica with a high content of OH radicals to increase transmission in the blue-visible spectral region. The length of the individual fibres is 2.8 m with a mean transmission of 96% between 350 and 900 nm. Two sets of fibres are available to minimize change over time. Thus, while exposing one plate, the next one can be prepared in the control room. In this way, changing field takes about 10 minutes.

The images of the objects lie directly on the input fibre ends. The core diameter of the fibres is 320 microns which provides a circular aperture of 2.3 arcsec. The input f/8 beam is degraded along the fibre in such a way that the f/6 collimator recovers 80% of the incoming light including absorption in the fibre and reflection losses at the fibre ends.

The equivalent "slit width" is determined by the core diameter of the fibre. On the CCD detector a single fibre is matched to 3.8 pixels (pixel size 27 μm) without taking into account the grating correction factor (anamorphism).

3.6.4 Boller and Chivens spectrograph

The usual f/8 collimator and the f/1.5 Schmidt camera of the Boller & Chivens spectrograph have been replaced by a dioptric f/6 collimator and an f/1.9 camera to improve the efficiency of the system.

The f/6 aperture of the collimator was chosen to compensate for the degradation of the f/8 Cassegrain beam by the optical fibres at the expense of a reduction in the resolving power. The collimator unit includes the shutter and a mask with order sorting filters (operated manually).

The f/1.9 camera replaces the Cassegrain Schmidt camera in order to avoid the central obscuration. The optical fibres tend to fill the central shadow of the secondary mirror in the telescope beam, so using the Schmidt camera is less efficient. Notice, however, that with the f/1.9 camera the dispersion of the gratings is reduced by $\sim$ 22%.

The f/1.9 camera provides an adjustment for focusing the spectra on the CCD.

Gratings

All gratings normally used with the Boller and Chivens and CCD detector can also be used with OPTOPUS. With OPTOPUS, however, the collimator/camera angle is increased by about 6° to a value of 55°, which has the effect of reducing the normally required setting angles of the spectrograph. The gratings are listed in Table 3.15.

3.6.5 Detector

A Tek 512×512 CCD (ESO # 32) detector with a pixel size of 27 μm is presently employed. The individual spectra cover approximately 4 pixels and the centre to centre separation between spectra is 6.4 pixels. For details, see Chapter 4 and the ESO CCD catalogue.

3.6.6 Performance

As a guide to the performance which can be expected from OPTOPUS, typical results obtained from scientific exposures are summarized below:

Table 3.12: OPTOPUS performance

Detector:	Tek CCD # 32	
Grating:	15 (17 nm/mm)	13 (34.1 nm/mm)
Wavelength range:	410 – 640 nm	337 – 848 nm
Resolution:	1 nm	2 nm
Exposure time:	60 min	60 min
Object magnitude:	B = 19 (galaxy)	B = 20 (quasar)
S/N obtained:	~ 50	~ 60

3.6.7 Guiding and calibration lamps

For guiding and alignment purposes, each starplate must also contain additional holes for up to 5 guidestars (selected by the astronomer during the preparation of the files), which are then observed from the control room by means of the coherent fibre bundles and the TV camera mounted on the OPTOPUS adapter. Engraved reticles cemented to the input ends of each guide bundle enable the observer to simultaneously correct translational and rotational alignments of the starplate. Autoguiding is done using the central image of the 5 stars.

The OPTOPUS adapter is fitted with three lamp housings for calibration exposures.

1. Quartz-halogen white lamp.
2. Philips helium source.
3. Philips argon source.

A Philips neon lamp can be mounted instead of either helium or argon lamps.

3.7 MEFOS

3.7.1 Introduction

The MEFOS Meudon-ESO Fibre Optic Spectrograph instrument enables the conventional use of the ESO Boller & Chivens spectrograph to be extended to multi object spectroscopy. The spectra of up 29 objects (together with 29 sky positions) inside the 1° field of the prime focus of the 3.6 m telescope can be simultaneously recorded onto one CCD frame by means of optical fibres.

The MEFOS positioning unit consists of 30 remotely controlled arms arranged on a circle around the flat field of the prime focus triplet. Each arm carries three fibres: one for the object, one for sky subtraction, and one imaging fibre bundle for object acquisition.

Arm one is dedicated to field acquisition and telescope guiding; it has two image fibres of different sizes. The acquisition unit guides the image fibres from each arm to a CCD viewing camera.

The 58 object and sky fibres are bundled and led to the spectrograph.

In order to observe objects in a given field it is necessary to prepare in advance a special file by using the celestial coordinates of the targets and running an interactive programme on any IBM compatible PC. At the telescope, after pointing to the centre of the field, the file is used to position the image fibre of each arm onto the corresponding target. Once the exact positions of the targets are automatically measured on the CCD, small offset motions of the arms bring the spectroscopic fibres into position and the exposure can be started. The whole acquisition and centering process takes about 10 minutes for galaxies of 19^{th} magnitude.

3.7.2 Spectrograph

The "Optopus" Boller & Chivens spectrograph is used. For details of gratings and spectrograph parameters, see the Optopus section (3.7) of this manual. The parameters are: slitlength = 17.5 mm projected to 11mm on the CCD; width of a spectrum = 85.1 μm$\equiv$ 3.2 pixels, spectrum separation: 182.8 μm=6.8 pixels.

3.7.3 Detector

The spectrograph is equipped with a Tek 512×512 pixels^2 CCD, ESO # 32. For details, see Chapter 4 of this manual or the ESO CCD catalogue.

3.7.4 Instrument parameters and performance

Telescope scale:	54.6 μm arcsec^{-1}
FOV:	1° or 196 mm diameter
Object and sky fibres :	135 μm = $2''.5$ diameter
length :	21 m
acquisition image fibres :	1.9×1.9 mm^2 = 36×36 arcsec^2
guiding image fibre :	8×6 mm^2 = 2.5×1.8 arcmin^2

The guiding fibre can be moved over a limited range (7.5×1.8 arcmin^2) near the edge of the field, allowing a suitable guidestar to be found. Guide stars should have $13 < V < 17$ approximately.

Test results are not available yet, but preliminary calculations indicate that MEFOS is ~ 25% more efficient than OPTOPUS. 21^{st} magnitude stars can be acquired using a 5 min. exposure.

3.7.5 Reference

Bellenger, R., et al.: 1992, The Messenger **65**, 54

3.8 Boller and Chivens spectrographs

3.8.1 Introduction

Boller and Chivens spectrographs (B & C) with CCD detectors are available for use at the Cassegrain focus of the 1.5 m ESO telescope, and for OPTOPUS and MEFOS at the 3.6m telescope (see Section 3.6 and 3.7).

The spectrograph optical design is shown schematically in Fig. 3.8. The light beam from the telescope passes through the slit and then, after collimation, is reflected off the grating and is finally imaged by a camera onto the CCD chip.

3.8.2 The B & C at the 1.5 m ESO telescope

The Boller & Chivens at the 1.5 m ESO has been equipped with a special dioptric camera for use with the f/15 telescope. It is now used with a high resolution Ford CCD. Acquisition and guiding are done using a CCD slit viewing camera, and an adapter allows remote instrument rotation. The instrument is fully controlled from the control room.

The 1.5 m ESO telescope, when used at Cassegrain, has a severe pointing limitation imposed by its pillars. For declinations $\delta \leq -45°$, or $\delta \geq -10°$ it is impossible to observe more than 30 minutes before the meridian when the telescope is on the east side of the polar axis and more than 30 minutes after the meridian when the telescope is on the west side. Changing the telescope from east to west and vice-versa is possible during the night, but is both delicate and time consuming. It takes approximately 40 minutes to make the change over and the support staff should be informed the day before (via the previous night's Operations Report) at what time you wish to switch over. However, because of the time lost, it is *strongly* recommended to avoid the change over during the night.

3.8.3 Slit assembly

The slit assembly consists of two 64 mm long polished and aluminized jaws on which the stellar image can be seen by reflection. They form a biparting slit that is continuously adjustable by a micrometer screw from 6 to 1200 μm. The scale is shown in Table 3.13.

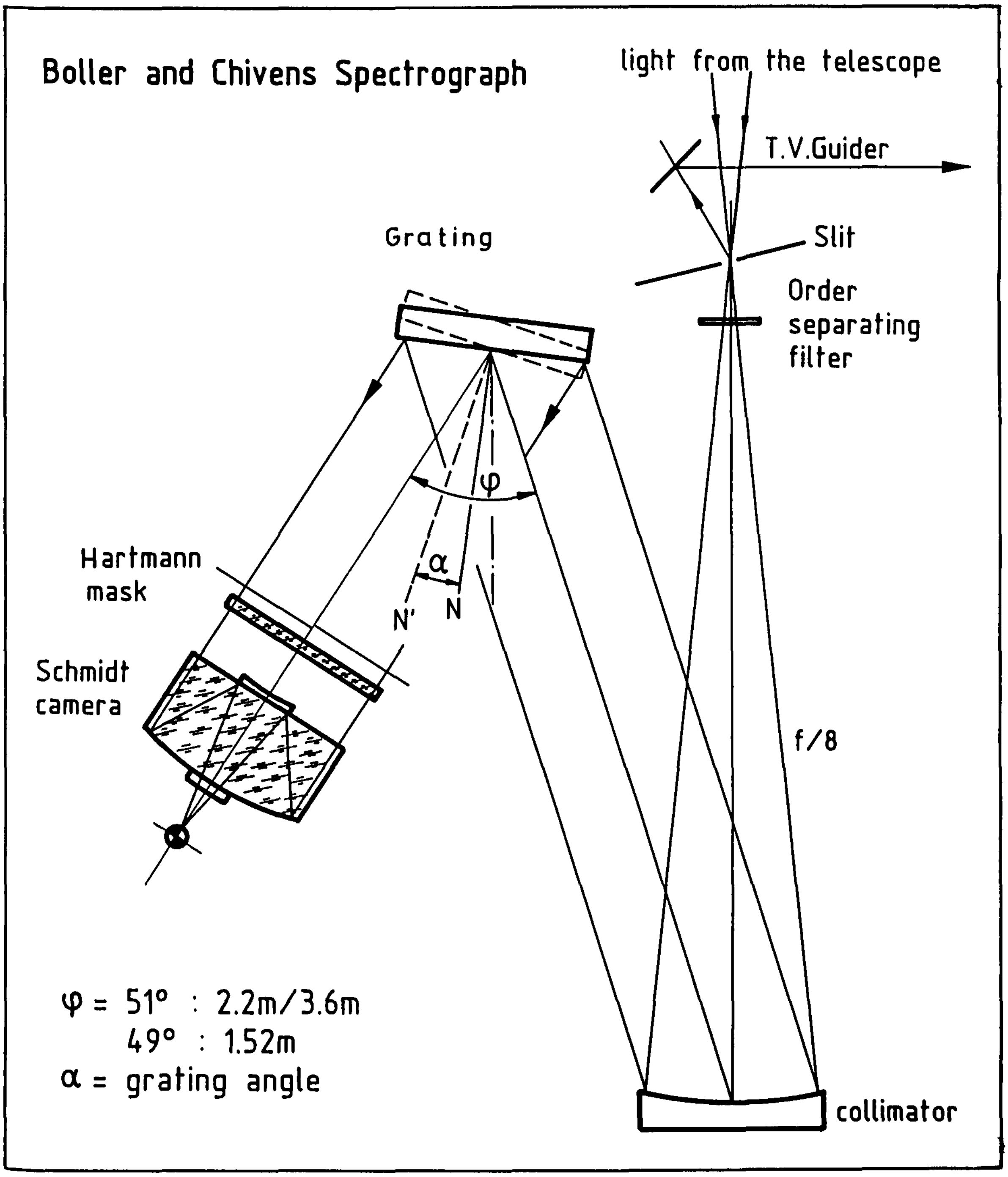


Figure 3.8: The Boller and Chivens spectrograph optics

Table 3.13: 1.5 m B & C optical parameters

Telescope f-ratio (f/)	Slit scale ($'' \mathrm{mm}^{-1}$)	B & C f-ratio (f/)	Collim. focal length (mm)	Grating conf. angle (°)	Camera focal length (mm)	Transversal magnification factor, γ
14.9	9.2	8.3	750	49	127	0.169

Note that the slit appears narrower to the detector depending on the grating angle. This effect, known as anamorphism, can be taken into account by selecting the resolution required at the detector and calculating back the slit width. The demagnification factor is shown in graphical form in Fig. 3.9.

3.8.4 Comparison sources

Comparison sources are provided for calibration. Helium + Argon and quartz halogen lamps are available.

3.8.5 Viewfinders and guiding

A CCD TV camera views the slit, giving a field for guiding of $1\rlap{.}'5 \times 1\rlap{.}'1$. Direct or integrating mode can be used for guide stars up to V = 20 mag on dark nights. Guiding has to be done manually.

3.8.6 Filters

Filters are available for selection of grating orders. The filter holder is placed after the slit and therefore the comparison spectra are also taken through the filter. For bright stars, a neutral density (ND) filter can be placed in the beam; however, this must be removed when exposing the comparison spectrum to have reasonable exposure times. ND filters can be changed quickly during the night.

3.8.7 CCD detectors

At present, the detector is CCD # 24 a high resolution coated Ford with 2048^2 pixels of 15 $\mu\mathrm{m}^2$. Note that this chip shows some remanence after severe over exposures.

For detailed information, see Chapter 4 of this manual and the Operating Manual # 12.

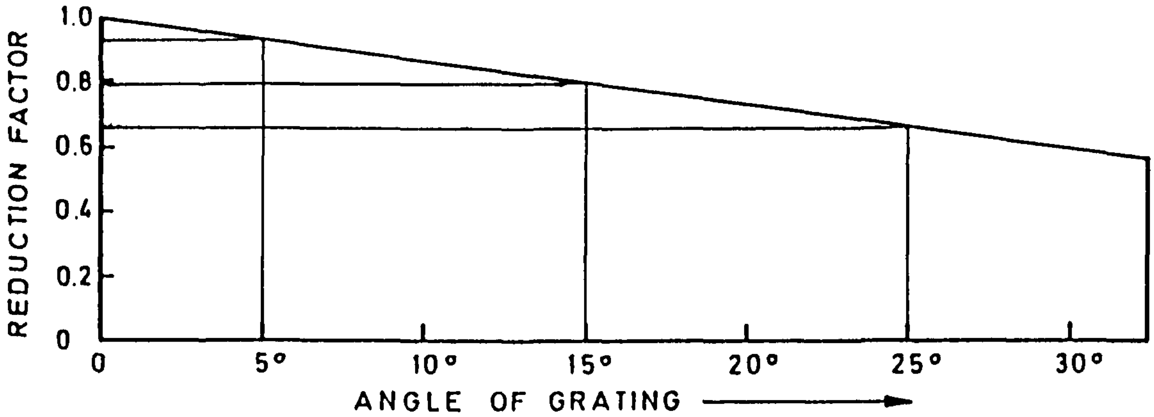


Figure 3.9: B & C grating demagnification factor

Table 3.14: 1.5 m B & C CCD detector parameters

Spatial scale ($''$ pixel^{-1})*	Slit length ($'$)	T.V. f.o.v.
0.81	4.2	$1'.5 \times 1'.1$

* 15 μm pixels

3.8.8 Gratings for B & C spectrograph

There are 31 gratings available for the B & C spectrograph. Dispersions range from 6.6 nm mm^{-1} to 50.8 nm mm^{-1} in first order. They are $110 \times 135\ \mathrm{mm}^2$ in size and mounted in a rotatable cell. Due to the 49° angle between collimator and camera, the blaze wavelengths are shifted to the blue by about 10%.

Gratings can be changed, but a change requires refocusing of the spectrograph. This is not recommended during the night since it takes up to 2 hours to complete the operation.

In Table 3.15 the available gratings are listed with their ESO number and 1st and 2nd order central wavelengths. Efficiency curves for all B & C gratings can be found in ESO Operating Manual # 9. To use a particular grating, a grating request form has to be filled out and deposited in the red box in the hotel entrance.

Note that some gratings produce ghosts (weak reflections of the main spectrum) especially those with blaze angles near 25°.

3.8.9 Grating efficiency

In order to select the gratings most suitable for a particular programme, it is useful to have an idea of the grating efficiency. The efficiency has been determined experimentally using a reflectometer for all gratings and efficiency curves are given in ESO Operating Manual # 9.

An approximate combined spectrograph/grating efficiency has been calculated. This assumes the slit width is matched to the seeing and detector pixel size. It takes into account geometrical vignetting due to grating, camera and the efficiency of the grating mount (shadow of each groove cast on the next). The efficiency of the grating is assumed to be 70 to 80% at the blaze angle and the optical transmission of the spectrograph has been estimated at 48%. The results of the calculations for efficiency variation with wavelength are shown for each grating in Fig. 3.10. These are all normalized curves, the relative efficiency between orders in some cases is still unknown.

References

- Heydari-Malayeri, M., Jarvis, B., Gilliotte, A., 1989, ESO Operating Manual # 9

Table 3.15: B & C spectrograph: available gratings

ESO #	Grooves mm^{-1}	Blaze angle	Order	Central wav. (nm)	OPTOPUS/MEFOS central wav. (nm)	Reciprocal dispersion ($nm\ mm^{-1}$)	OPTOPUS/MEFOS dispersion ($nm\ mm^{-1}$)
1	225	5°20′	I	723.6	732.9	33.7	23.1
			II	361.8	366.5	16.8	11.6
2/15	300	4°18′	I	455.0	443.4	25.3	17.4
3/17	400	9°44′	I	770.0	749.8	19.5	13.4
			II	385.2	374.9	97.7	6.7
4/6	600	13°0′	I	682.5	665.1	13.1	9.0
			II	341.2	332.5	6.6	4.5
5	900	21°10′	I	723.6	711.7	8.8	6.0
			II	361.8	355.9	4.4	3.0
7/23	600	8°38′	I	455.0	443.8	13.1	8.8
8/24	400	4°30′	I	364.0	348.0	19.3	13.3
9/18	300	8°38′	I	910.0	887.7	25.8	17.7
			II	455.0	443.9	12.9	8.8
10/19	600	17°27	I	910.0	886.6	13.3	11.5
			II	455.0	443.3	6.7	4.6
11/20	1200	36°52′	I	910.0	887.0	6.6	4.5
			II	455.0	443.5	3.3	2.2
12/22	1200	26°45′	I	682.5	665.4	6.7	4.6
			II	341.2	332.7	3.4	2.3
13	150	2°09′	I	455.0	443.7	50.9	34.9
14	400	13°54′	I	1200.0	1065.4	19.4	13.3
16/21	400	6°54′	I	540.0	532.8	19.4	13.3
25	400	6°30′	I	515.0	502.1	19.4	13.3
26	1200	22°12′	I	573.0	558.6	6.7	4.5
27	600	11°21′	I	597.0	581.9	12.9	8.8
			II	298.5	290.9	6.4	4.4
28	600	17°27′	I	909.6	886.6	12.9	8.8
29/30	600	5°10′	I	300.0	266.3	12.9	8.8
31	1200	10°22′	I	300.0	266.0	6.8	4.5

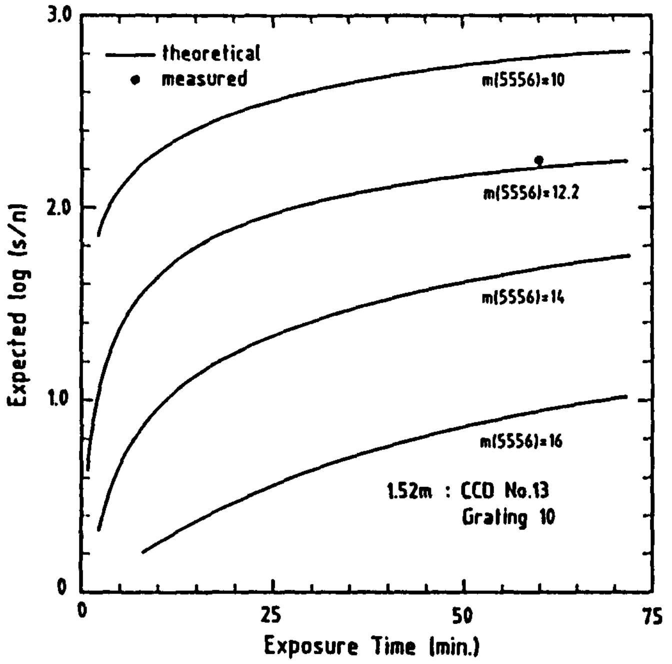


Figure 3.10: B & C spectrograph efficiency curve: expected S/N ratio vs exposure time for the 1.52 m telescope at 555.6 nm.

3.9 EMMI

3.9.1 Introduction

The ESO Multi Mode Instrument or EMMI is installed at adapter B on one of the Nasmyth foci of the NTT.

EMMI has red- and blue-optimized arms, each equipped with a CCD camera. The instrument is mounted on the NTT instrument rotator/adapter, which contains the autoguider and calibration lamp facilities.

EMMI is controlled from the NTT control room using a mouse driven program. The data from the CCDs goes to IHAP and a SUN workstation running MIDAS under UNIX. Storage is on 6250 BPI tape in FITS format, but an Exabyte 8200 unit is available with the MIDAS workstation. The La Silla tape services including archiving however, uses the 6250 BPI tapes.

EMMI has five modes of operation:

RILD or red imaging and low dispersion spectroscopy

BIMG or blue imaging

REMD or red medium dispersion spectroscopy

BLMD or blue medium dispersion spectroscopy

DIMD or dichroic medium dispersion spectroscopy (this is REMD and BLMD simultaneously by means of a dichroic beam splitter)

Each mode is discussed below.

3.9.2 Observing modes

1. RILD In this mode, using the red arm, one can do:
    (a) Direct imaging using any of the EMMI filters, listed in Table 3.16.
    Note that these filters are 85 mm in diameter. The field is 10 × 10 armin^2 with the Loral 2048 chip. Focusing is done with a focus wedge, similar to the EFOSC instruments. A MIDAS batch interactively computes the necessary offset to be given to the telescope focus. The variation of the telescope focus with temperature is 0.076 units per °C. The filterwheel has 9 positions, one is free, and 8 can be used for filters. The short wavelength cut-off in the red arm is at 400 nm.
    (b) Single slit spectroscopy with grisms.
    By selecting a slit in the aperture wheel, which is in the focal plane of the telescope, and a grism in the grism wheel, low resolution spectroscopy can be done. There are six grisms available, which are listed in Table 3.17.

Table 3.16: EMMI filters (85 mm diameter)

ESO	Filter	$\lambda_0/\Delta\lambda$ (Å)	Peak Efficiency	Availability	Focus Offsets
587	He I	4480/50	55	yes	−22
588	He II	4692/66	72	yes	−97
589	O III / 0	5014/56	64	yes	−2
590	O III / 3000	5057/64	52	yes	+7
591	O III / 6000	5112/61	69	yes	−5
592	O III / 9000	5160/63	68	yes	26
593	O III / 12000	5211/67	66	yes	0
594	O III / 15000	5260/66	65	yes	−3
595	N II / 0	6609/73	57	yes	0
596	H Alpha / 0	6570/72	52	yes	+19
597	H Alpha / 3000	6634/65	63	yes	34
598	H Alpha / 6000	6694/68	57	yes	20
599	H Alpha / 9000	6763/69	53	yes	30
600	H Alpha / 12000	6834/72	61	yes	35
601	H Alpha / 15000	6896/72	62	yes	−6
602	U	3540/540	67	yes	40
603	B	4230/940	65	yes	0
604	B (2)	4230/940	65	yes	
605	Bb	4150/1100	67	yes	−2
606	V	5420/1050	84	yes	+36
607	V (2)	5420/1050	84	no	
608	R	6450/1550	79	yes	0
609	R (2)	6450/1550	79	no	
610	I	8000/1580	94	yes	+6
611	Z	cut on 8420	85	yes	+4
643	BG38 2mm	4800/3200	97	yes	
644	GG375 3mm	cut on 3700	98	yes	
645	OG530 3mm	cut on 5300	98	yes	0
646	RG715 3mm	cut on 7220	98	yes	
647	Ne V	3427/82	42	yes	
648	O II / 0	3730/67	92	yes	
649	O II / 5000	3799/67	45	yes	
650	O II / 10000	3858/69	43	yes	
651	O II / 15000	3924/76	40	yes	
652	He II	4696/73	61	yes	
653	N II / 0	6590/31	57	yes	
654	H Alpha	6562/31	40	yes	
655	S II / 0	6732/72	60	yes	
656	9150	9137/194	92	yes	
657	S III / 0	9532/100	93	yes	
658	EUV (UG11/5)	3280/750	71	yes	
659	ND 0.3			yes	
660	ND 0.3			no	
661	ND 0.5			yes	
662	ND 0.5			no	
663	ND 1.0			yes	
664	ND 1.0			no	
665	ND 2.0			yes	
666	ND 2.0			no	
667	ND 3.0			yes	
668	ND 3.0			no	
669	ND 4.0			yes	
670	ND 4.0			no	

Table 3.17: *EMMI grisms.*

Grism #	**g/mm**	**Blz. ang (deg)**	**Blz. λ (nm)**	**Eff. (%) 1)**	**Disp. (nm/mm) 2)**	**Rs 3)**	**Wavelength range (nm) 4)**	**Disp (nm/pix) 2)**
1	150	8.6	560	79	51.5	350	390 – 1200	.76
2	300	14.6	490	78	24.6	730	390 – 960	.36
3	360	15.0	460	77	20.0	960	390 – 894	.30
4	300	22.0	650	72	23.8	940	390 – 1100	.36
5	600	34.0	530	66	11.2	1400	390 – 6970	.17
6	600	54.0	650	55	10.2	2100	538 – 8620	.16

Notes:

1) Efficiency at blaze.
2) With F/2.5 camera. Divide by 2.12 for F/5.3 camera.
3) Resolution with $1''$ slit at 600nm (at central λ for grisms 4, 5, and 6).
4) With F/2.5 camera and Loral 2048 CCD.

Acquisition of an object is done by taking a direct image of the field. A MIDAS batch is used interactively to identify the object, and combined telescope/autoguider probe offsets are then given to put the target on the slit at the required position.

When two objects have to be observed simultaneously, another batch allows the position angle of the instrument to be determined. The instrument is then rotated to this angle and the same procedure followed as for a single object.

(c) Slitless spectroscopy

By using a grism with a free aperture instead of a slit, slitless spectroscopy can be done. To shorten the spectra, a filter can be used together with the grism.

(d) Multiple object spectroscopy

By taking a direct image of a field containing several objects of which spectra are desired, multiple object spectroscopy can be done using EMMI. The direct image is used to interactively define the various slitlets at the positions of the targets. This is done on the workstation using the MIDAS context `emos`. The unit to make the slitlets is permanently mounted in EMMI, and will produce the slits in real time. In this way several spectra can be taken on one CCD frame.

Note that the spectral range will be determined by the positions of the slitlets with respect to the centre of the CCD.

2. BIMG Blue imaging.

Here the instrument is used as a normal straight through adapter in a converging beam. Focus has to be made using a through focus exposure or taking a focus in the RILD mode and giving a (known) offset to obtain the blue focus.

3. REMD Red grating spectroscopy.

In this mode grating or echelle spectroscopy at intermediate dispersions can be done.

The instrument is used as a classical spectrograph with the RILD focal reducer as camera. See Figure 3.11 for the light path in EMMI.

The gratings available are shown in Table 3.18.

Table 3.18: *EMMI gratings.*

Housing	Grating #	g/mm	Blaze angle (deg)	Blaze λ (nm)	Eff. (%) 1)	Disp. (nm/mm) 2)	Rs – 3)	Use in arm	λ range 4) (nm)	Remarks
A	1	—	—	—	—	—	—	blue	—	Mirror
	4	300	3.6	400	72	7.2	840	blue	170	
B	3	1200	13.9	380	65	1.75	3400	blue	46	
	5	158	1.8	370	72	1.50	400	blue	250	
C	11	3000		350	~50	0.61	11000	blue	12	
	12	600		350	~65	3.78	1700	blue	75	
D	6	1200	21.0	550	72	2.80	5500	red	85	
	7	600	11.3	600	68	5.60	2600	red	118	5)
E	2	—	—	—	—	—	—	red	—	Mirror
	9	60	28.7	all	50–72	1.83	7700	red	grism	5)
F	10	31.6	63.5	all	52–65	0.5	28000	red	grism	5)
G	8	316	6.8	620	70	10.86	1300	red	332	5)
	13	150	2.2	550	68	23.0	600	red	710	

Notes:

1) Absolute efficiency at blaze.
2) With F/4 (blue) and F/2.5 (red) cameras. Divide by 2.1 for F/5.3 camera in the red.
3) Resolution with 1″ slit at 400 nm (blue) or 600 nm (red).
4) Wavelength range is recorded with the F/2.5 camera and LORAL 2048 CCD (red), and F/4 camera and TEK1024 CCD (blue). The wavelength range with the echelles is determined by the grism used as cross-disperser which also sets the order separation.
5) Second order overlap may occur in the red beyond 780 nm; use an order sorting filter.

Units E and F should be used with a grism as cross disperser. The combinations are listed in Table 3.19.

A slit of variable width and variable length (by means of a movable dekker) is used for grating spectroscopy.

The acquisition of an object which is visible on the intensified camera viewing the slit is simple: by eye the object is placed on the slit. Objects down to V = 18 can be seen and centered. For fainter targets a direct image in RILD is taken, a brighter field star selected and a blind offset done from this field star to the object. The NTT offsets are accurate to $\sim 0\farcs1$ over short ($< 60''$) distances.

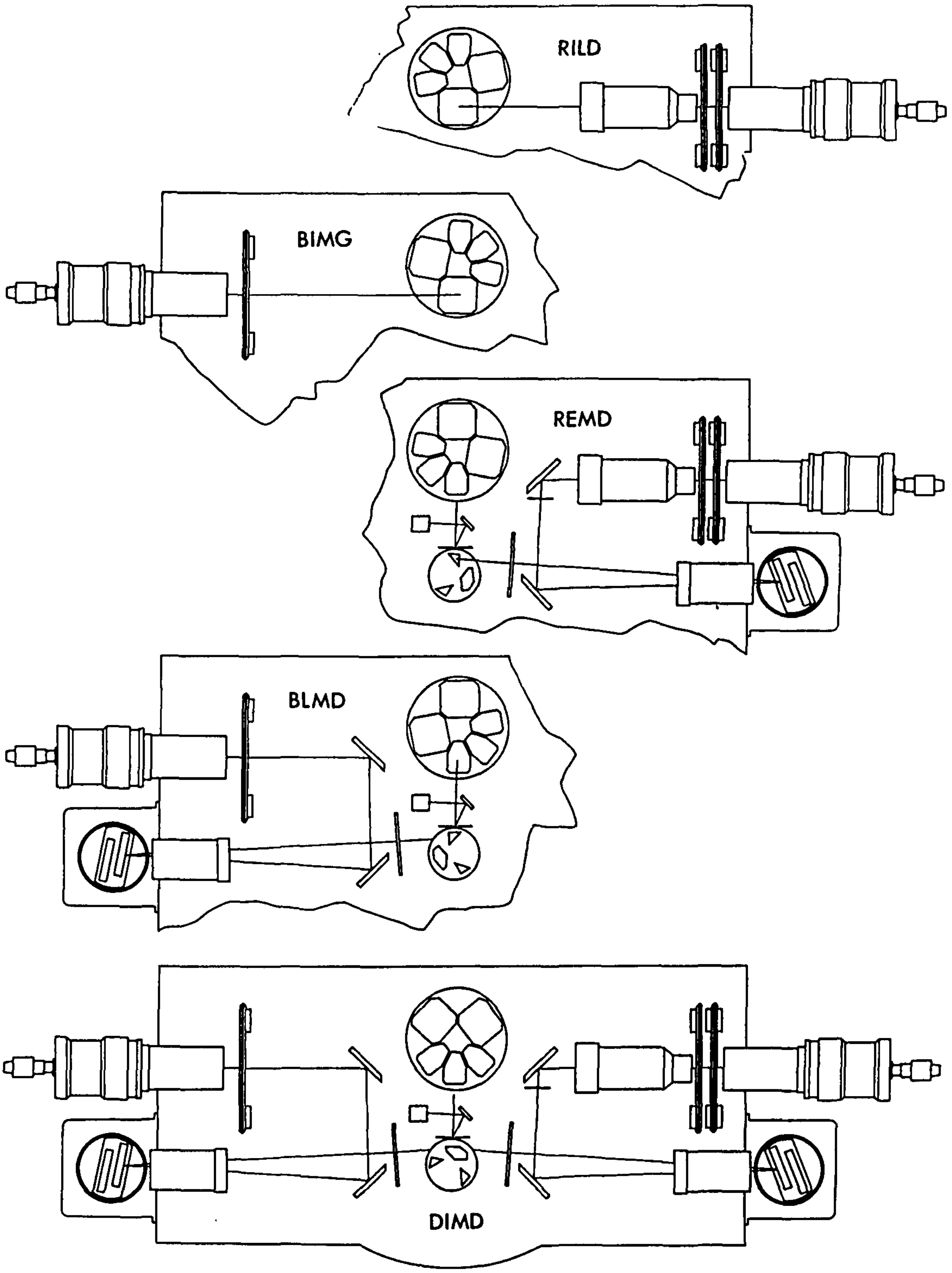


Figure 3.11: EMMI: light path

Table 3.19: *Echelle spectroscopy with EMMI.*

GRATING #9		
Grism CD	**Wavel. range * (nm)**	**Mean resolving power**
3	390 – 854	8500
4	483 – 1100	8500

GRATING #10		
Grism CD	**Wavel. range * (nm)**	**Mean resolving power**
3	390 – 890	35000
4	498 – 1100	35000
5	390 – 697	35000
6	565 – 865	35000

* Using the F/2.5 camera and a 1.″2 slit with the LORAL 2048 CCD.

4. BLMD This mode is basically the same as REMD but for the blue arm. The gratings available are listed in Table 3.18.

   Note that one unit can be mounted, giving one or two gratings available per night.

   Acquisition is as for REMD mode.

5. DIMD In the dichroic mode, REMD and BLMD can be used simultaneously. The object is centered as for the REMD mode and the light is split into a red and a blue beam by the interposed dichroïc. Two exposures are defined and two spectra are obtained at the same time.

   It is (at present) necessary to make the exposure times sufficiently different, so that the two CCDs are not read-out simultaneously as they interfere with each other, increasing the noise levels.

   Notice that this mode produces a focus offset in relation to BLMD and REMD.

3.9.3 Detectors

At present, EMMI is equipped in the red arm with a LORAL 2048 chip with 2048 × 20482048 pixels^2 of 15 μm^2 each, giving a scale of 0.34"/pix pixel^{-1}. In the blue arm there is a Tektronix TK1024M chip with 1024 × 1024 pixels^2 of 24 μm^2 each, giving a scale of 0.″37 pixel^{-1}. For details of both these CCDs, see Chapter 4 of this manual or the ESO CCD catalogue.

3.10 SUSI

3.10.1 Introduction

The SUperb Seeing Imager or SUSI is a direct CCD camera for imaging at high resolution. The instrument complements EMMI and is mounted on the NTT adapter A, on the same Nasmyth focus platform as IRSPEC.

SUSI has a filterwheel with 9 positions, which can hold 60 mm diameter filters. For a complete list of available filters see Chapter 4 of this manual and the ESO filter list of imaging quality filters. Filters dedicated to SUSI are listed in Table 3.20.

Table 3.20: SUSI basic set of filters

ESO # type	ESO # type	ESO # type
640 U	703 Gunn g	707 [OIII]
639 B	704 Gunn r	708 Hα
641 V	705 Gunn i	709 665.4 cont.
642 R	706 Gunn z	710 [SII]

SUSI is designed for use when the seeing is better than about $0\farcs7$ FWHM and switching from EMMI to SUSI takes about 5 minutes.

3.10.2 Observing

SUSI is controlled from a terminal in the NTT control room and shares the tape unit and the SUN workstation with EMMI.

Focusing is done as for the EMMI BIMG mode, by making a through focus exposure.

3.10.3 Detector

At present, SUSI is equipped with a Tektronix TK 1024M CCD with 1024 × 1024 pixels^2 of 24 μm^2 each. The pixel scale is $0\farcs13$ pixel^{-1}. For details of the CCD (ESO # 25) see Chapter 4 of this manual.

3.11 IRSPEC

3.11.1 Introduction

IRSPEC is a cryogenically cooled scanning grating spectrometer equipped with a 58 × 62 pixel^2 SBRC InSb array with 76 μm pixel size. It covers the 1 μm to 5 μm wavelength range at resolving powers of between 1000 and 5000. The instrument is attached to one of the f/11 Nasmyth foci of the NTT and hence is free of instrumental flexure effects. It employs an optical de-rotator in front of the slit to counter the field rotation at the telescope focus and to permit orientation of the slit at any position angle on the sky.

IRSPEC is remotely controlled from an HP 1000/A990 computer via form filling and 'mouse' clicking on a menu bar. An on-line display of standard instrument and detector status parameters is shown on a Ramtek screen.

3.11.2 Instrument description

Figure 3.12 shows a schematic view of the instrument.

Light enters the instrument via the de-rotator. After passing through the entrance window, the f/8 beam is converted to f/7.4 by a field lens in front of the slit which also re-images the pupil onto a cold stop at the off-axis parabolic collimator. The latter directs the 10 cm diameter collimated beam onto one of the two back to back mounted gratings of 300 and 600 lines/mm and 12 × 15 cm^2 ruled area, which are operated in the Littrow mode. The f/2 Pfund camera then focuses the spectrum onto the detector array.

The gratings can be interchanged by means of an 180° rotation. The gratings can also be rotated about an axis parallel to the ruled surface for wavelength scanning. Both gratings have blaze angles of $\sim 37°$ and can be scanned over $\sim 25°$.

The slit is $2'$ long and variable in width. The magnification factor between detector and slit is 3.7 so that a 76 μm detector element corresponds to 280 μm or $2.''2$ at the slit. The slit is polished and inclined, allowing it to be viewed by a TV camera. Behind the slit is a wheel with 8 positions containing the order sorting filters.

3.11.3 Detector

The detector is a Santa Barbara 58 × 62 pixel^2 In-Sb array. Each pixel is 76 μm square, projecting $2.''2$ on the sky. Its RQE is 89% at 2.85 μm and 99.7% of the pixels are functioning. The pixels have a full well capacity of 10^6 e^-.

The dark current of the array at 30K is ~ 200 e^- s^{-1}, while the internal instrumental background adds in to give ~ 400 e^- s^{-1} in total. For details of the read-out methods, see the IRSPEC manual.

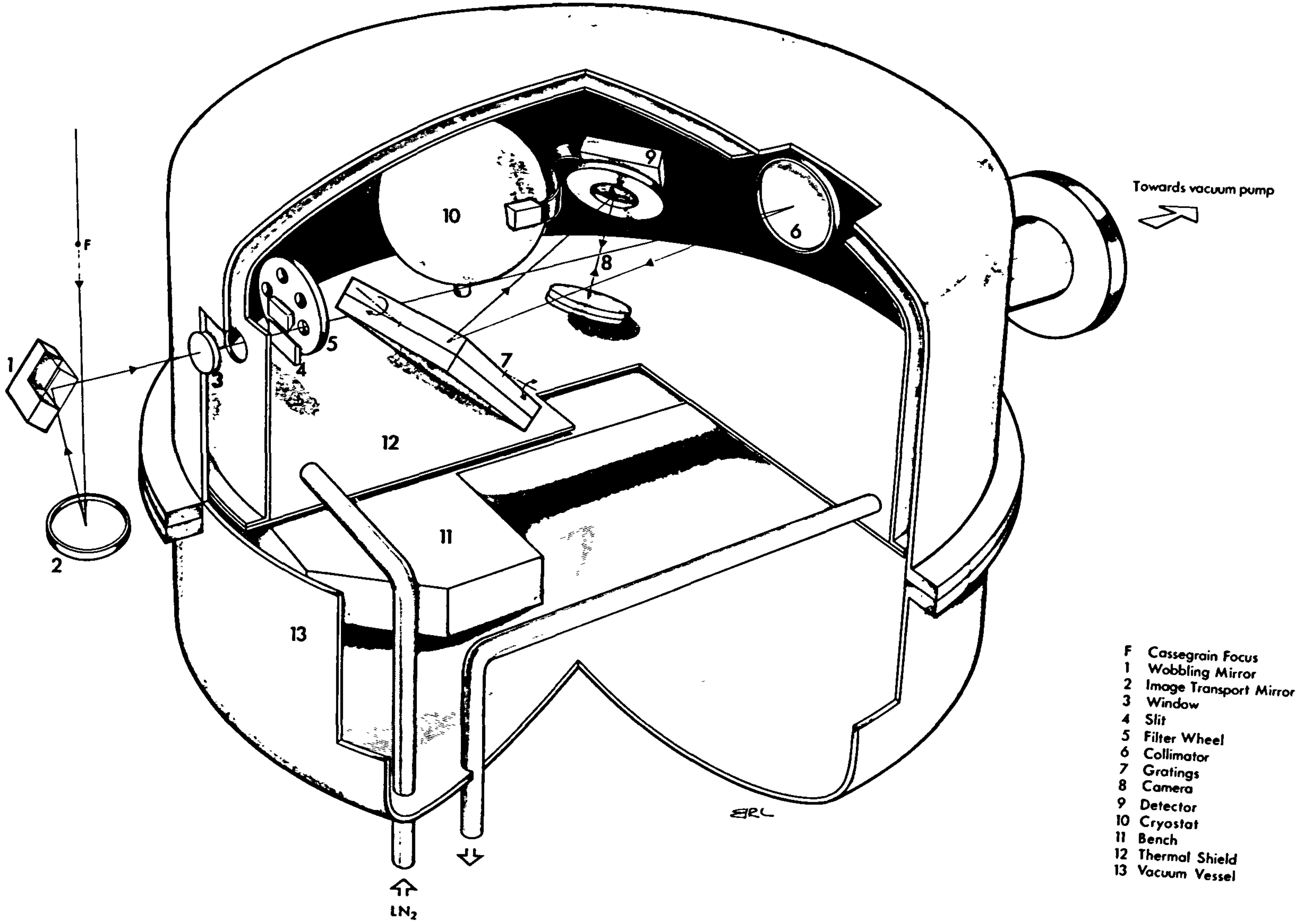


Figure 3.12: Schematic of IRSPEC

3.11.4 Cryogenics

The optical elements are cooled to $\sim$80K by a continuous flow of liquid N_2 from an internal reservoir which needs refilling about every 17 hours. The detector is cooled to $\sim$ 30K by a closed cycle He-cooler.

3.11.5 Software

The data are stored on disk and magtape in IHAP format including all relevant telescope information, IRSPEC settings and comments in the file header. IHAP is available on-line and data reduction and analysis can be done during observations. Examples of observing procedures and complete lists of commands are given in the IRSPEC manual.

3.11.6 Performance

Table 3.21 shows the approximate sensitivity of IRSPEC used in various modes. On-source and sky integrations of 60s are assumed.

Table 3.21: IRSPEC Performance

Grating	*λ-range*	*Order*	*Filter*	*Resolution*[a]	*Sensitivity (1σ in 60 sec)*	
	mum				*mag*	10^{-21} *W cm*$^{-2}$
1	1.05 – 1.4	3	2	1500 – 2200	14.0	2.6
1	1.07 – 1.3	4	2	2300 – 3400	13.2	3.2
1	1.5 – 1.8	2	3	1400 – 1800	15.1	0.6
1	1.5 – 1.7	3	3	2400 – 3400	13.1	1.8
1	2.0 – 2.6	2	4	2000 – 3400	13.2	1.0
1	3.0 – 5.2	1	7	1400 – 3400	8.0[d]	33[d]
2	1.05 – 1.3	2	2	2200 – 3400	14.2	1.3
2	1.4 – 2.0	1	3,8[b]	1300 – 2000	15.2	0.6
2	1.8 – 2.6	1	4,6[c]	1700 – 3400	14.0	0.5

[a] for a slit width of 560μm, corresponding to two pixels

[b] 1.41 – 1.52μm: Filter 8

[c] 1.81 – 2.04μm: Filter 8

[d] 3.6μm, 0.5 sec

References

- Moorwood, A.F.M. et al., 1986, ESO Messenger, No. 44, 19
- Gredel, R., Moorwood, A.F.M., 1991, IRSPEC, (ESO Operating Manual # 10)

3.12 IRAC 2

3.12.1 Introduction

IRAC 2 is an IR camera installed at the f/35 infrared adapter of the 2.2m telescope. The camera has 5 objectives to allow a suitable pixel scale to be selected, and for use with different detector arrays. Note that the maximum available field (as defined by the camera input window), is $\sim 200''$ so that severe vignetting occurs with lenses D and E. The available filters are listed in Table 3.22. The camera is available with the laboratory control software and the installation of the final software is foreseen for the end of 1992. An HP workstation is used to control the instrument, and MIDAS is available for on-line data handling and reduction.

Table 3.22: IRAC 2 filters

Name	$\lambda_c(\mu m)$	$\Delta\lambda(\mu m)$
J	1.25	0.3
H	1.65	0.3
K	2.2	0.4
K′	2.1	0.34
BP1 [FeII]	1.262	0.04
BP2 [FeII]	1.645	0.04
BP3 HeI	2.058	0.036
BP4	2.105	0.037
BP5 H_2	2.121	0.039
BP6	2.136	0.038
BP7	2.148	0.037
BP8 Brγ	2.164	0.037
BP9	2.177	0.038
BP10	2.216	0.075
BP11 CO	2.365	0.088
Fabry-Perot	2 – 2.5	$\lambda/\Delta\lambda \sim 10^3$ (tunable)

Table 3.23: IRAC 2 pixel scales and FOV

Objective	arcsec/pixel^{-1}	FOV ($''$)
A	0.15	38 × 38
B	0.27	72 × 72
C	0.49	136 × 136
D*	0.80	diam. =200
E*	1.1	diam. =200

* vignetted

3.12.2 Detector

The camera is equipped with a Rockwell Hg:Cd:Te NICMOS3 array of 256 × 256 pixels^2 of 40 μm each. The array is sensitive from 1 μm to 2.5 μm and has a QE of 40% at 1.25 μm increasing to 60% at 2 μm. The read-out noise is ~ 40 e$^-$ and the dark current is ~ 15 e$^-$ s^{-1}. The cosmetic quality is very good, with only 0.6% bad pixels, most of which are along a bad column .

3.12.3 Performance

The overall system efficiency is 18-19% through the broadband JHK filters.

Observations are normally carried out by taking many pairs of object and sky frames and then computing the difference.

Using objective C, under background limited conditions (easily achieved through the broadband filters) and in $1''$ seeing, one can expect to detect a point source of K=18.5 and an uncertainty of ± 0.2 mag in 1 hour total integration time (i.e. 6 pairs each of 3 min on source and 3 min on sky). This can be compared to the average brightness of the sky at K which is 11.8-12.1 mag/arcsec^2, depending on the season.

For some examples of what has actually been achieved, see the references.

References

- – Moorwood, A.F.M. et al., 1992, The Messenger **69**, 61
- – Guarnieri, M.D. et al., 1992, The Messenger **70**, 44
- – Storm, J., Moneti, A., 1992, The Messenger **70**, 50
- – Peletier, R.F., Knapen, J.H., 1992, The Messenger **70**, 57
- – Block, D., Grosbøol, P., Moneti, A., Patsis, P., 1992, The Messenger **71**, 41

3.13 Adapter at the 2.2 m telescope

3.13.1 Introduction

The adapter has 2 filter wheels, holding up to 8 filters of 60 mm diameter or 51 mm square size. Any suitable filter from the imaging quality filter catalogue can be selected.

There is a standard ESO autoguider. The instrument can be rotated manually in the dome; the angle is read off a Vernier scale on the adapter.

The scale is $11''.65$ mm^{-1} at the focal plane or $0''.17$ pixel^{-1} (15 μm pixels).

3.13.2 Detector

The adapter has an RCA HR chip with 1024 × 660 pixels^2 of 15 μm^2 (ESO #8). For details see Chapter 4 of this manual.

3.14 Infrared photometers

3.14.1 General introduction

Infrared photometers/spectrophotometers are available at the 3.6 m, 2.2 m and 1.0 m telescopes. A bolometer for wavelengths in the range 2 $\mu m \leq \lambda \leq 25$ μm and an InSb system for wavelengths 1.2 $\mu m \leq \lambda \leq 5$ μm may be mounted together on the photometer. The photometers at all three telescopes are very similar in design and differ only in details. The 3.6 m and 2.2 m telescopes are equipped with f/35 chopping secondary mirrors while the 1 m has a focal plane chopper.

All three telescopes have drive systems with the necessary pointing accuracy essential for IR work and for daytime observing. The telescopes can be programmed to beam switch and raster scan.

Observations are scheduled for both day and night time observing. An operator is normally available to assist the VA with the observing at the 1 m telescope.

The earth's atmosphere absorbs a large part of the infrared. This is due principally to absorption by water vapour in the atmosphere. Plots of the atmospheric transmission at La Silla are shown in Fig. 3.13. These were computed by G. Finger at ESO, and correspond to 1 mm of precipitable H_2O above La Silla. Also shown are the central wavelengths and designations of the principal infrared photometric bands.

The IR passbands have been named using letters from Johnson's system: J, H, K, L, M, N, Q. It can be seen from Fig. 3.13 that M and Q are not specially good windows and often these bands give the first indications of impending poor weather.

Approximate extinction at La Silla is:

1.25	1.65	2.2	3.6	4.8	8.1	9.5	12.1	19.6	λ μm
0.08	0.06	0.11	0.13	0.27	0.2	0.15	0.05	0.45	mag/airmass

At infrared wavelengths, the sky and telescope radiate strongly. A chopper is employed to separate this background signal from the astronomical signal. The chopper allows the photometer to see alternately one of two beams: one, generally referred to as A, containing the object, sky and telescope; and the other, B, the reference beam containing sky and telescope. The two beams are distinguished by phase sensitive detection. The difference between the signals in the two beams would, to a first approximation, give the object flux. However, the beams are rarely perfectly balanced. To overcome this, the telescope is

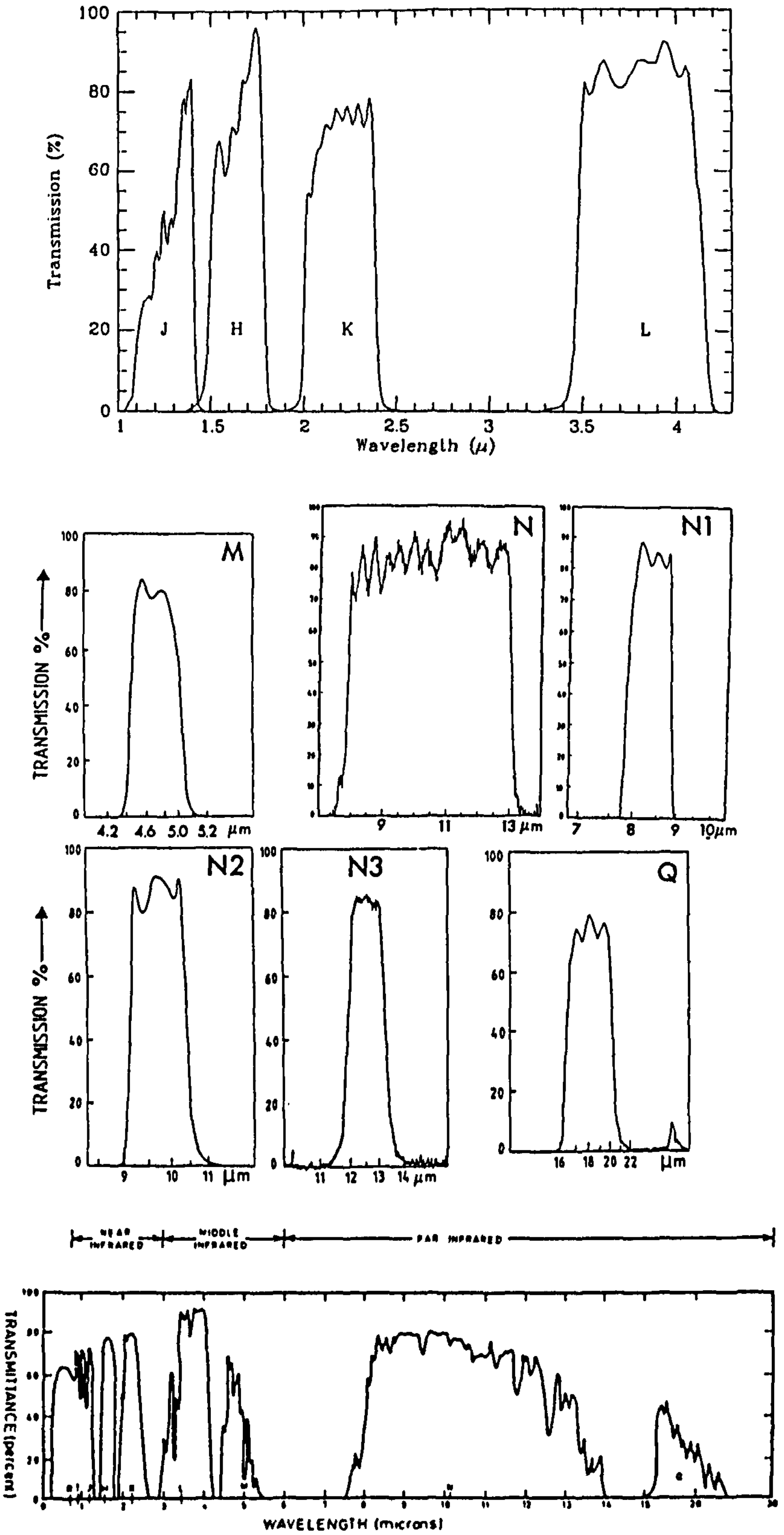


Figure 3.13: IR atmospheric transmission at La Silla

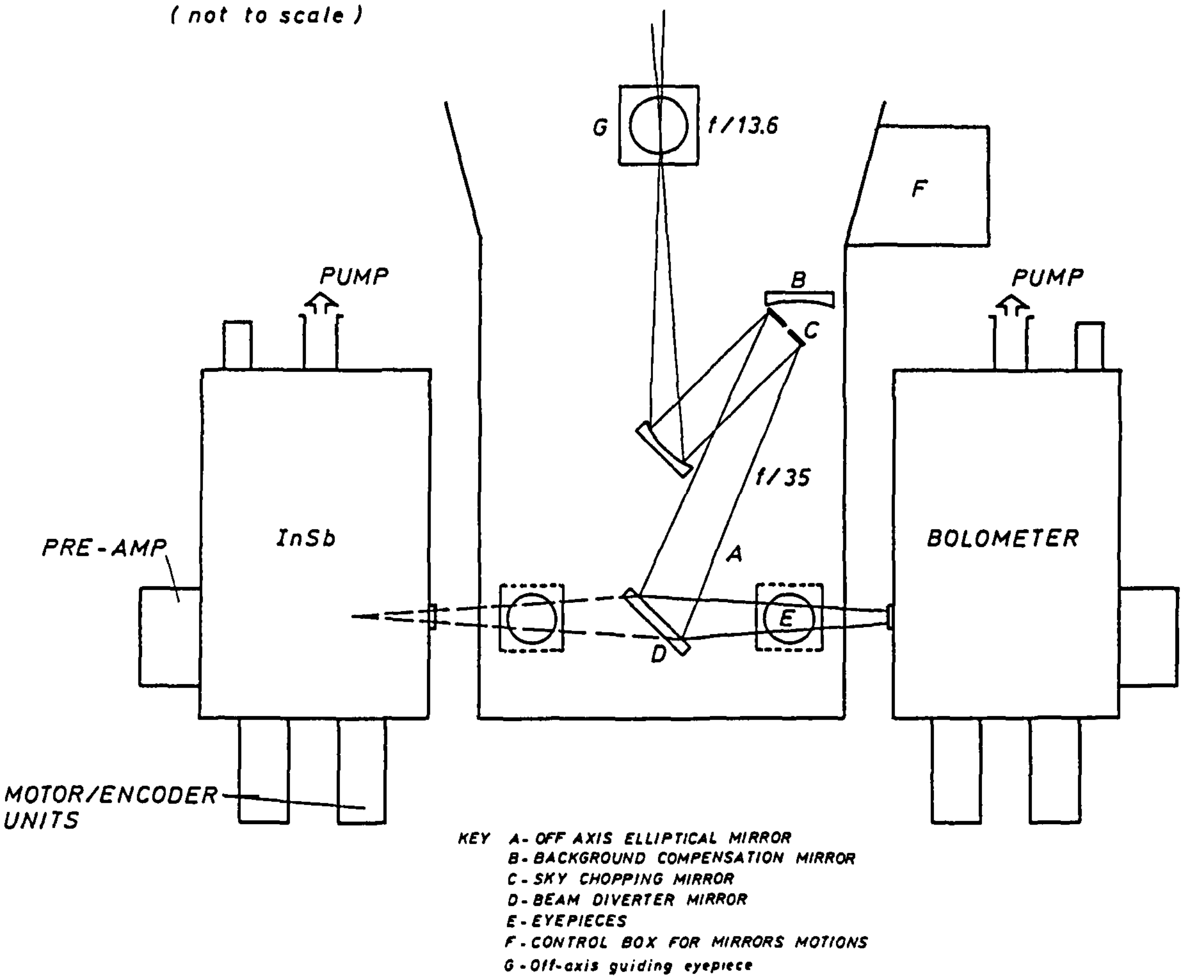


Figure 3.14: Schematic layout of IR photometer at the 1 m telescope

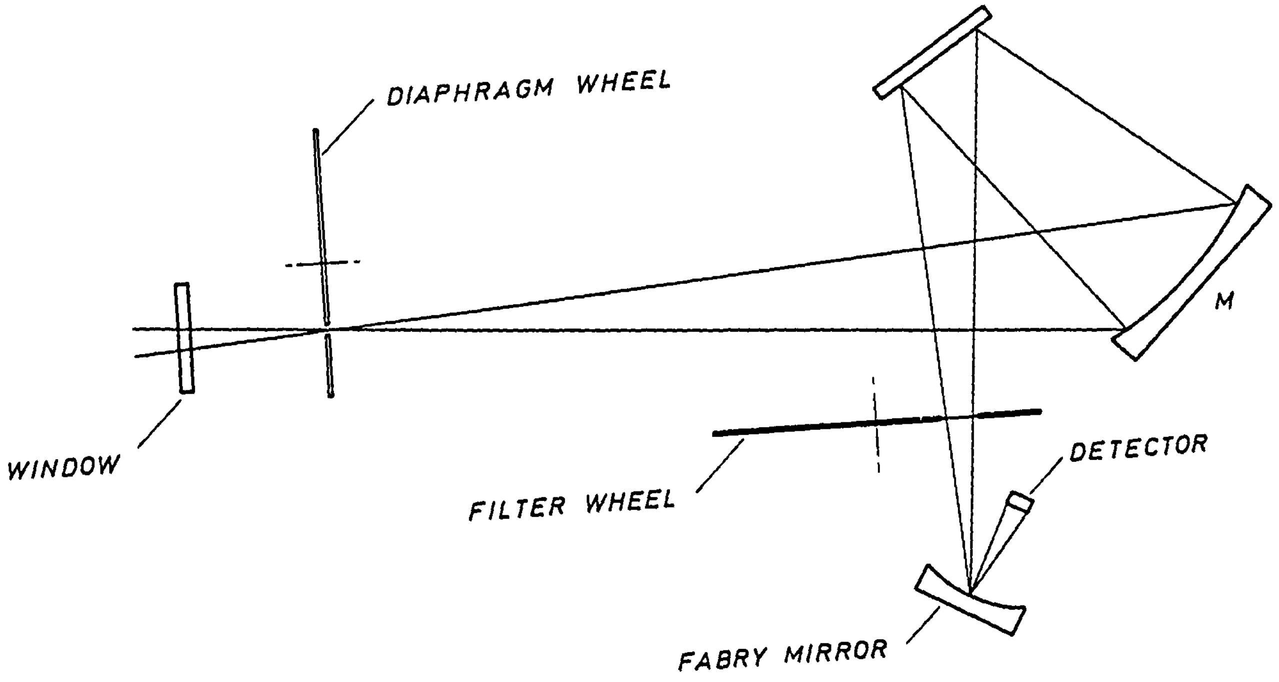


Figure 3.15: IR photometer: cold optics

moved to place the object in the other beam. This is called beam switching and is carried out automatically.

The detectors, filters and photometer optics are mounted in cryostats cooled by solid N_2 in the case of InSb, and by means of pumped liquid He in the case of the bolometer.

3.14.2 Filters and diaphragms

Available broad band filters and narrow band ($\lambda/\Delta\lambda \sim 70$) circular variable filters (CVFs) are listed in Table 3.24, and diaphragms in Table 3.25.

Table 3.24: Filters and CVFs (InSb and bolometer)

InSbs			Bolometers		
Name	$\lambda_c(\mu m)$	$\Delta\lambda(\mu m)$	Name	$\lambda_c(\mu m)$	$\Delta\lambda(\mu m)$
J	1.24	0.2	K	2.18	0.4
H	1.63	0.3	L	3.78	0.7
K	2.19	0.4	M	4.66	0.7
L	3.78	0.7	N	10.36	5.2
M	4.66	0.5	N1	8.36	0.85
			N2	9.67	1.65
K0	2.24	0.5	N3	12.89	1.4
LA	3.64	0.9	Q0	18.56	4.1
			Q1	>19.7	
			Q2	>23	

Note: K0 and LA are not mounted in all photometers.
Filters are not identical in all bolometers.

CVFs		CVF
CVF 1	1.5 – 2.5 μm	CVF 8 – 14 μm
CVF 2	2.5 – 4.5 μm	
CVF 3	4.1 – 5.5 μm	

3.14.3 Performance

The limiting magnitudes for the IR photometers have been determined using test observations. *Note that the actual values will depend strongly on weather conditions.* The noise contribution from the detector is dominant at J and H, that of the telescope emission at L and N, and that from sky emission at M and Q.

Day time observing degrades the limiting magnitudes in J, H and K by at least 3 mag.

For an object to be visible on the chart recorder and amplifier, it has to be about 6 mag brighter than the limiting values.

Table 3.26 lists the limiting mag and sky brightness for 1σ in 30 min integration time.

Table 3.25: Circular diaphragms (InSb and bolometer)

Name	Diameter			
	mm	arcsec		
		3.6 m	2.2 m	1 m
D1	6	10	16	30
D2	4.5	7.5	12	22.8
D3	3.0	5	8	15.2
D4	2	3.3	5.4	10
D5	1	1.65	2.7	5

Note: Rectangular apertures of 1 × 6 mm^2 and 3 × 6 mm^2 are also mounted.

Warning: The values given for the diaphragms are nominal. The actual sizes depend on the beam profiles of each detector. If important for your observations, *measure their real sizes before starting observations* by stepping across a bright star in α and in δ with 0″.5 steps.

Table 3.26: Limiting magnitudes and sky brightness (1σ in 30 min integration time)

Band	3.6 m (D = 7″.5)	2.2 m (D = 8″)	1 m (D = 15″)	Sky (mag arcsec^{-2})
J	20.6	19.8	17.4	16
H	19.8	19.3	16.9	14
K	19.0	18.4	15.9	12
L	14.7	13.8	11.9	3
M	11.7	11.0	9.1	0
N	8.8	7.4	6.2	
Q	4.5	3.5	2.4	

Note: Limiting magnitudes for CVFs are about 3 mag brighter in the corresponding bands and are different for detector and background limiting bands.

3.14.4 Standard stars

A list of 250 standard stars is available for broad band photometry and CVF spectrophotometry. This list is stored in a file accessible via the `INFO` command. The telescope can be automatically preset to the position of any star in this list. If on-line magnitudes are required, then the zero points of the system must first be determined by observing any of these standard stars.

The list of standard stars is mainly based on Koornneef, (1983, A&AS Ser. 51, 489) and Allen (A.A.O. Users Manual). Bolometer values are added from various sources (e.g. Thomas, Hyland and Robinson, 1973, MNRAS 165, 201) and 20μm magnitudes (Q0) added for stars from Morrison and Simon (1973, AJ 186, 193). Observers preferring to use their own standards should note that the InSb detector saturates on stars with $K \leq 1.5^m$ at the 1 m, and proportionally fainter stars at the 3.6 m and 2.2 m.

References

- Bouchet, P., 1989, ESO Operating Manual # 11
- Bouchet, P., 1989, "Reduction programmes for IR photometry on La Silla"
- IR techniques: "Methods of Experimental Physics", vol. 12, 1973, Ed. N. Carleton
- f/35 control software: 1985, ESO Maintenance Manual # 3

3.15 CES

3.15.1 Introduction

The CES was designed for high resolution ($50\,000 \leq R \leq 200\,000$) spectroscopy with good photometric accuracy and linearity. Fig. 3.16 shows the layout of the instrument. The CES is used with a CCD as detector.

The whole optical wavelength range is covered and two fully optimized optical trains, one for the blue, one for the red regions, are available. The switch between red and blue takes less than 10 minutes and can easily be done by the night assistant during the night. The ranges are: blue 340 – 530 nm, red 500 – 1200 nm.

There are two cameras available: the short camera, of f/2.6 and the long camera, of f/4.7.

The CES is located in the 3.6 m building Coudé room and can be fed by the Coudé Auxiliary Telescope (CAT) or via a fibre link by the 3.6 m telescope. Normally the CAT is used. Note that the CAT has pointing restrictions (see Fig. 2.9).

The spectrograph is a classical Czerny-Turner echelle with a Littrow mounted prism as predisperser.

3.15.2 Acquisition and guiding

A 15 cm telescope attached to the CAT provides, via an intensified TV camera, an acquisition field of 20′ × 27′ which is only useable for quite bright stars. The large field on the slit viewer is $2\overset{\prime}{.}3 \times 3\overset{\prime}{.}2$ and the small field 46″ × 62″. An autoguider is used on the slit viewer. Three colour filters (red, green, blue) can be positioned in front of the TV camera for accurate guiding at large zenith distances (see Users' Manual for details). Offset guiding is possible only for short exposures since the field rotates during exposures.

3.15.3 Calibration

Up to 8 calibration sources can be fed into the spectrometer via a remotely movable mirror. The following sources are available:

1. Fe-Ne hollow cathode lamp.
2. Th-Ar hollow cathode lamp.
3. Ne low pressure lamp.
4. Hg low pressure lamp (for alignment).
5. Quartz-iodine lamp 8V/50W (2800° K) for flat fielding.
6. He-Ne laser for instrumental profile recording.

At present, the last two positions are free.

One of a series of neutral density filters can be selected via the CES control program to give the appropriate intensity for each wavelength setting and calibration source.

3.15.4 Slit

The slit consists of two symmetrical jaws which provide a slit width adjustable between 100 μm and 5 mm. The scale at the slit is 226 μm arcsec^{-1}. A decker in front of the slit allows the slit to be set to lengths between 3″ and 20″.

3.15.5 Echelle gratings and predisperser

The CES echelle grating is 204 × 408 mm^2 and has 79 lines mm^{-1} with a blaze angle of 63°26′. The predispersers are prisms optimised for blue and red passbands for maximum transmission. *Only one order is observed at a given setting.*

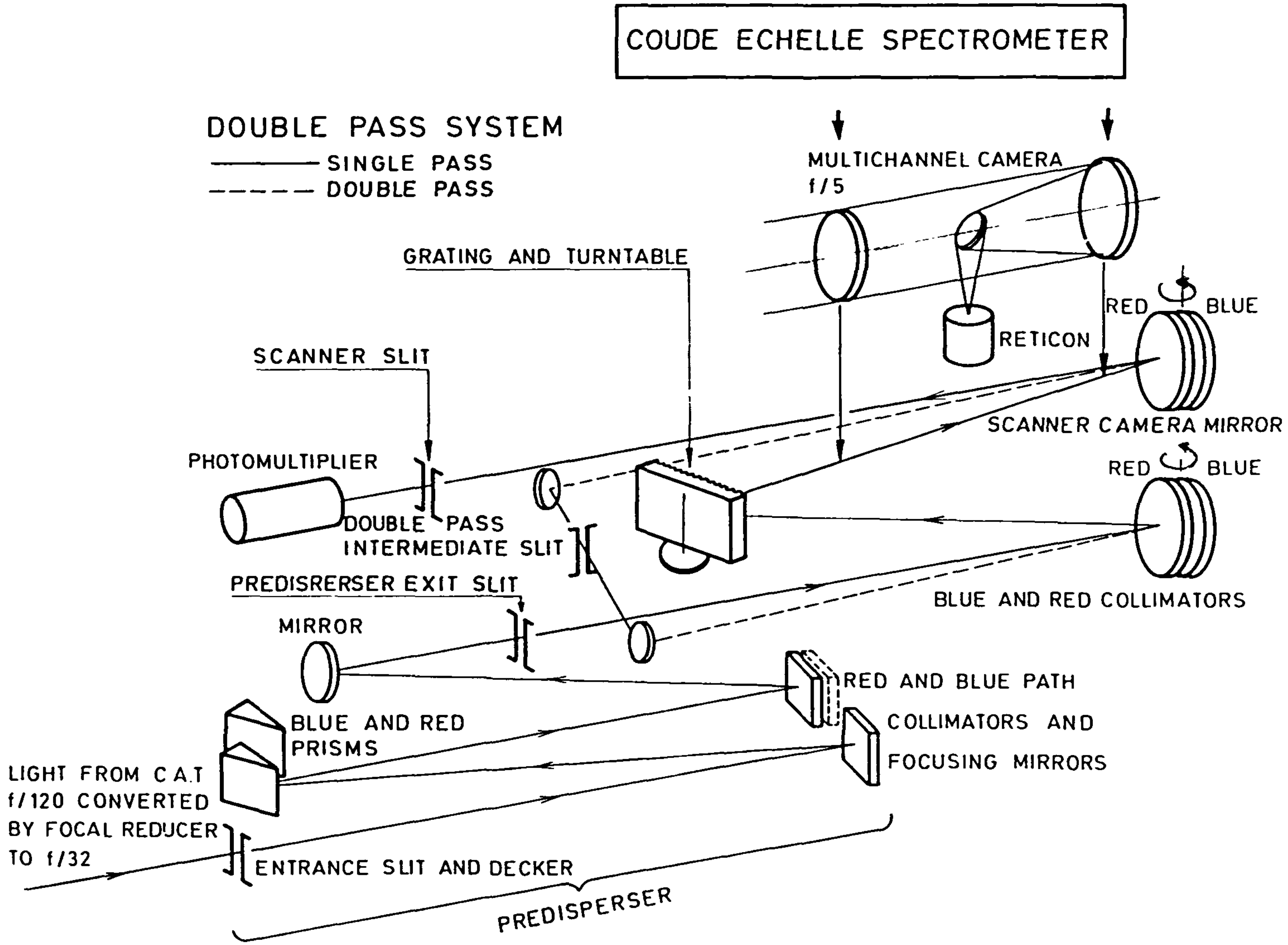


Figure 3.16: CES: schematic of instrument

3.15.6 Cameras

The short camera is f/2.6 with a focal length of 516.5 mm and gives a linear dispersion of 0.26 nm mm^{-1} at 500 nm. One CCD frame covers about 4 nm and the spectral resolving power lies between 30 000 and 60 000. Pixels of 15 μm correspond to $1''.02$ and $0''.83$ along and across the slit respectively.

The long camera is f/4.7 with a focal length of 942 mm and has a linear dispersion of 0.145 nm mm^{-1} at 500 nm. Pixels of 15 μm correspond to $0''.56$ along and $0''.45$ across the slit. Resolving powers of up to about 110000 can be achieved.

3.15.7 Detectors

The CES uses CCD # 9 with the short camera. This is a high resolution (1024 × 640) thinned back-illuminated RCA type. It has excellent charge transfer and needs no preflash. The dark current is < 3 e^- per hour, and the readout noise is about 35 e^-. For the long camera, CCD #30 is used. It is a coated FORD with 2048 × 2048 pixels^2 of 15 × 15 $\mu\mathrm{m}^2$. With this CCD the spectral coverage of the long camera is 10% larger than that of the short camera, with a resolving power almost twice as large.

For details of the CCDs, see Chapter 4 of this manual.

Light not passing through the exit slit of the predisperser is reflected to a photon counter which acts as an exposure meter. Once the optimum exposure has been determined for a particular programme, the counter can be used to determine your exposure times or monitor the conditions of the exposure, e.g. loss of light due to seeing deterioration or high cirrus, etc. *Note that the monitor does not measure at the actually observed wavelength region; it must be calibrated for every central working wavelengths and for every spectral type observed.*

3.15.8 Control

Control of the telescope and instrument including changing wavelength range (but not change of red/blue paths) is fully remote. An HP computer with disk and tape units handles the data acquisition. IHAP can be used; a graphics terminal, Ramtek B/W image display, and plotter are available in the control room adjacent to the slit room and Coudé room in the 3.6 m building. Instruments and telescope control takes place mainly using menus accessed to by softkeys, providing a user friendly instrument.

3.15.9 CES performance

The overall instrument efficiency is shown in Table 3.27 for the CCD with short and long cameras.

Table 3.27: Overall efficiency of the CES + CAT

Wavelength	350 nm	403.5 nm	443.5 nm	540 nm	645 nm	809.2 nm
Short Camera + CCD	0.26%	5.5%	9.1%	12.5%	12.5%	6.2%
Long Camera + CCD	—	—	—	3.8%	4.6%	2.2%

Figs. 3.17 and 3.18 show the expected S/N as a function of V magnitude and exposure time for the CCD/short camera and long camera combinations respectively. Increase of the achievable S/N with respect to the illustrated expectation through on-chip binning is at most marginal (less than 20%) even for the faintest sources.

References

- Enard, D., 1979, ESO Technical Report No. 10
- Lindgren, H., Gilliotte, A., 1989, ESO Operating Manual # 8

3.16 Fibre link to CES

3.16.1 Introduction

For objects too faint for the CAT/CES combination, or to achieve new high S/N ratios on bright objects, it is possible to use the 3.6 m telescope with an optical fibre link to the CES. The fibre is mounted in the centre of the OPTOPUS adapter (see section 3.6) at the Cassegrain focus. A micro lens adapts the f/8 beam from the 3.6 m telescope to the fibre. The fibre entrance face subtends $3\farcs4$ on the sky. At the fibre output the beam is converted to f/32 and an image slicer puts the light into the CES slit.

Either the short or long camera can be used. Resolving power is set by the image slicer; 4 slicers are available. There are four fibres available; the optimum choice is determined by the employed image slicer and by the observed wavelength. Change overs can only be done during the day.

3.16.2 Observing

The acquisition and guiding is done in the 3.6 m telescope control room while the instrument control is done from the CES control room.

The fibre aperture with microlens is mounted below an inclined mirror diaphragm, allowing centering and offset guiding of objects.

Calibration spectra and flat field exposures are made by illuminating the fibre aperture by a lamp: thorium for spectral calibrations and halogen for flat fields. Observing is generally the same as for the CAT/CES combination.

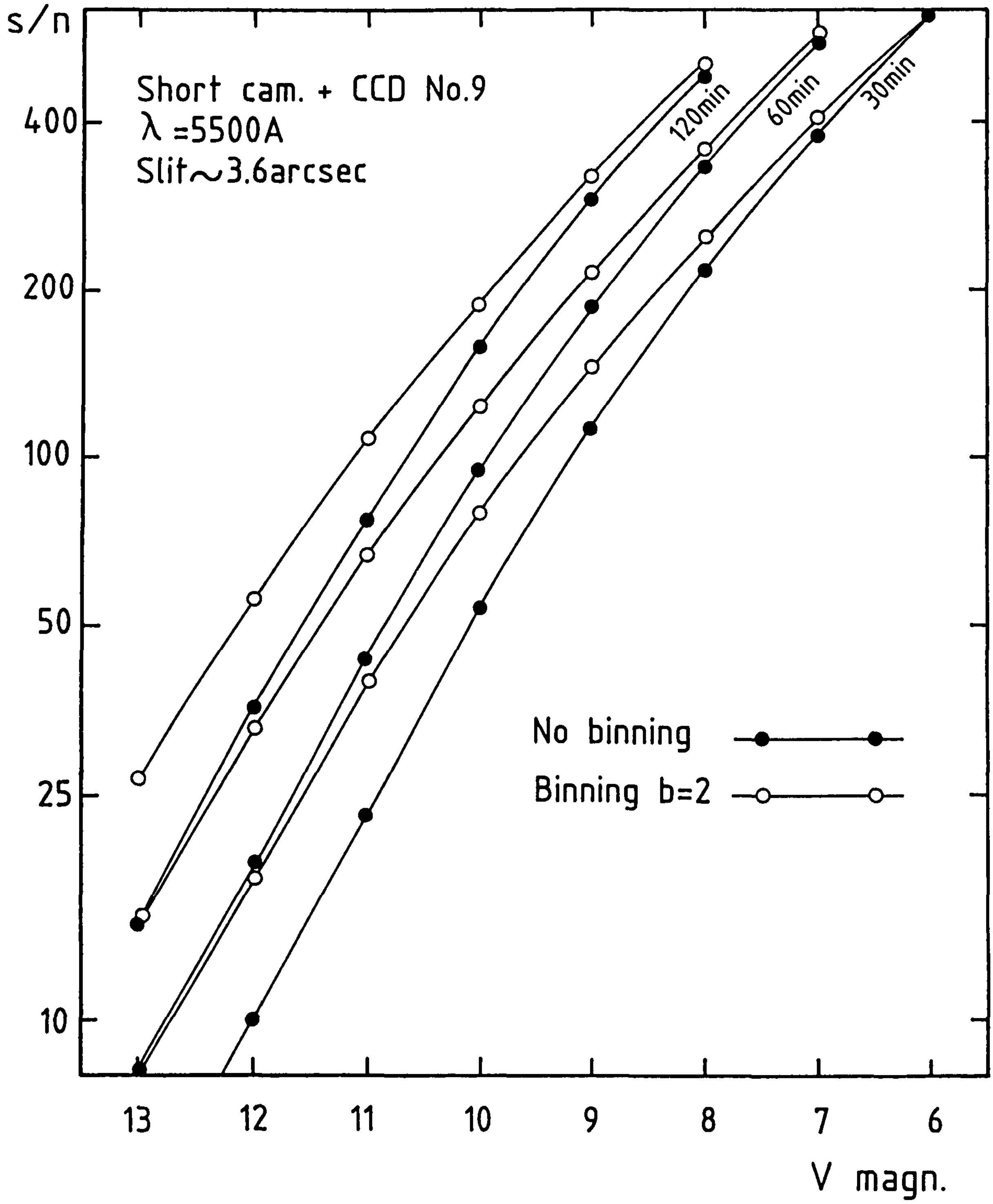


Figure 3.17: CES: CCD/short camera efficiency

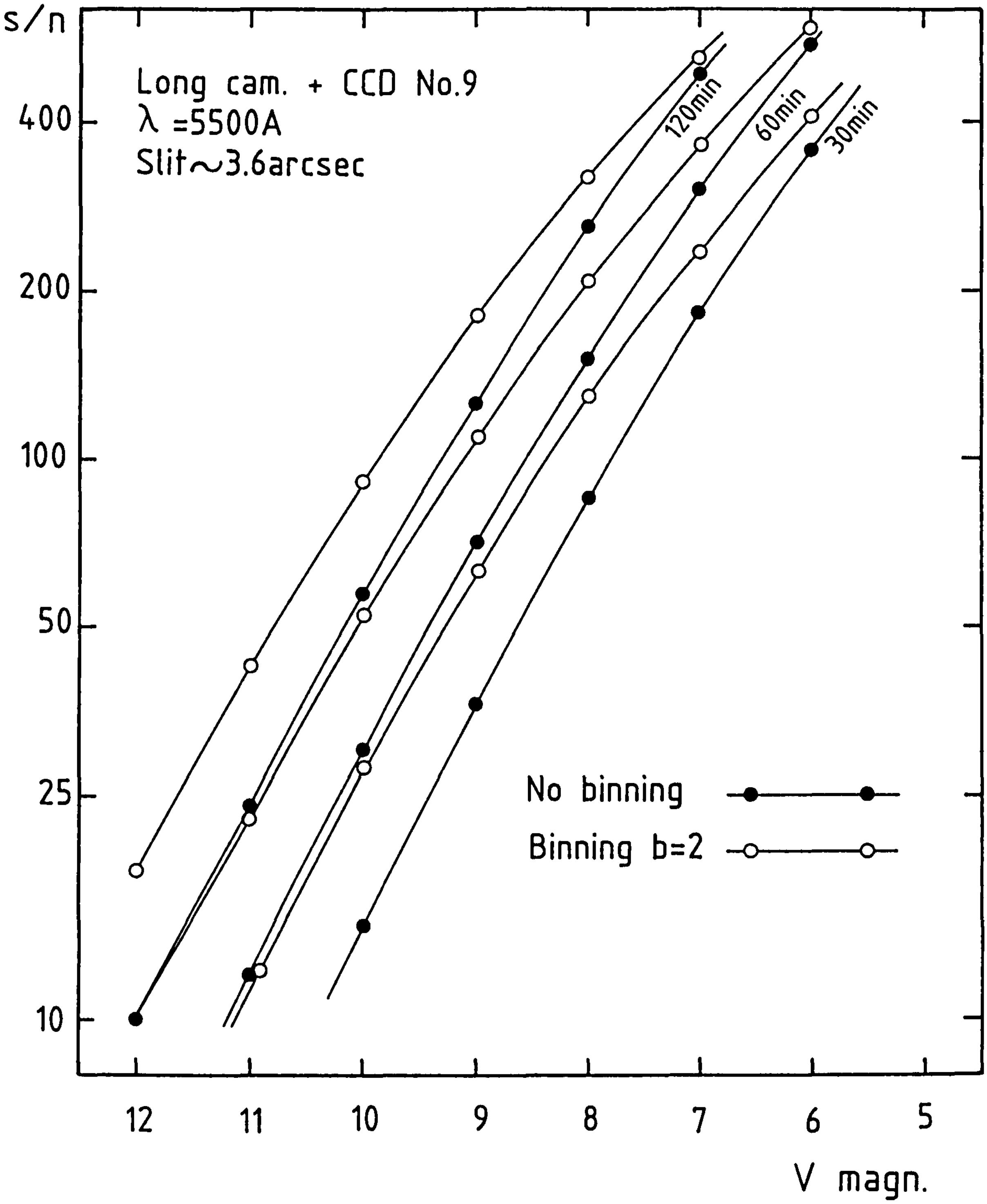


Figure 3.18: CES: CCD/long camera efficiency

3.16.3 Performance

The gain of the 3.6 m/fibre/CES over the CAT/CES is about 1.5 magnitudes in the 500–700 nm wavelength range. This corresponds to about 1 photon nm^{-1} s^{-1} detected at 590 nm for a star with $m_{(5900)} = 16.5$. This value depends only weakly on the seeing for seeing < 3″ FWHM. At 400 nm the value is $m_{(4000)} = 15.6$.

For faint objects binning along the slit can improve the S/N. Since this is mainly dependent on the readout noise, 3 × 1 binning is useful. Higher binning (up to 8) may also be used.

Note that at the 3.6 m offset guiding is possible unlike with the CAT where the field rotates during exposures.

References

- G. Avila, S. D'Odorico, 1988, ESO Conference on Very Large Telescopes, p. 1121

3.17 Adapter at the 1.54 m Danish telescope

3.17.1 Introduction

At the 1.5 m Danish telescope the two filter wheels will hold: (a) 13 filters of ≤ 60 mm diameter and (b) 7 filters of ≤ 110 mm diameter. One position in each wheel remains free.

Any imaging quality filter can be selected and there is a dedicated "basic set" consisting of filters: U(#632), B(#450), V(#451), R(#452), Gunn g(#459), Gunn i(#461), Gunn z(#462). Also interference narrowband filters: [OIII](#690), Hα(#693), Hα red(#697), and [SII](#701).

The autoguider is not the standard ESO type and guide star selection is not as straight forward as at the 2.2 m. In the VAX 750, a guide star programme (`NGUIDE`) allows selection of nearby, suitable guide stars which can be found at the telescope by entering the given probe offsets. MIDAS and IHAP are available for on line data reduction. The guide star selection has to be done before observing starts. The image scale at the 1.5 m Danish is $0\farcs28$ $pixel^{-1}$ of 24 μm or $18\farcs66$ mm^{-1}.

The instrument can be rotated.

3.17.2 Detectors

At present, Tektronix 1024^2 CCD with 24 μm^2 pixels (CCD #28) is used at the 1.5 m Danish telescope. For details of these chips see Chapter 4 of this manual or the ESO CCD catalogue.

References

- H.E. Schwarz, 1992, ESO Operating Manual # 12, CCDs
- A. Gilliotte, 1990, Imaging Quality Filters Catalogue

3.18 Adapter at the 0.91 m Dutch telescope

3.18.1 Introduction

The adapter has 2 filter wheels holding 7 filters each, with one free position. Filters have a diameter of 60 mm or are 51 mm square. All suitable imaging quality filters can be used, and there is a dedicated "basic set", which consists of: U(#634), B(#419), V(#420), R(#421), Gunn g(#463), Gunn r(#464), Gunn i(#465), Gunn z(#466), [OIII](#688), Hα(#387), Hα red(#389), and [SII](#391).

The instrument is controlled from a PC in the control room. At present, there is no communication between the adapter, TCS, and CCD programs.

3.18.2 Detector

At present, the adapter is equipped with a Tektronixs CCD (ESO #33) with 512 × 512 pixels^2 of 27 μm^2. For details of the CCD, see Chapter 4 of this manual.

The scale is $0\farcs443$ pixel^{-1}.

3.19 Photoelectric photometers

3.19.1 General information

The following photometric systems are currently supported on La Silla.

- Johnson UBV
- Cousins UBVRI (uniform sets of filters based on refs. 2, 5)
- Strömgren uvby (uniform sets of filters based on refs. 3, 6)
- Hβ wide/Hβ narrow (uniform sets of filters based on refs. 4, 7)

Standard filters, photomultipliers, data acquisition programs (with on-line magnitude determination), and reduction software are available for these photometric systems. Other photometric systems can be used by the VA made up either from the ESO filter list, or by filters provided by himself. All ESO photometers use photon counting electronics.

Output of the data acquisition programs is on magnetic tape. For observatory supported systems, the data can be reduced at the computing centre by means of the general purpose photometric reduction program `SNOPY`. The observer should normally consider staying some days after his/her observing run in order to complete the data reduction. *Data reduction is not carried out by ESO staff.*

ESO Operating Manual # 16, Photoelectric Photometers, gives a complete list of references which may help observers in preparing observing programmes.

3.19.2 Photomultiplier tubes

The list of photomultipliers available on La Silla is given in Table 3.28.

Table 3.28: Photomultiplier tubes available on La Silla

Photomultiplier	*Cathode*	*Cooling*	*System*	*Telescope*
EMI 6256[†]	S–11	Dry ice	UBV	0.5 m ESO
EMI 9789Q	Bialkali	Uncooled	uvby, UBV	1 m, 0.5 m ESO
EMI 9658R	S–20[*]	Dry ice	UBVRI	3.6 m, 1 m, 0.5 m ESO
RCA 31034 (Quantacon)	Ga-As	Peltier	UBVRI	3.6 m, 1 m, 0.5 m ESO
Hamamatsu R943-02	Ga-As	Peltier	UBVRI	3.6 m, 1 m, 0.5 m ESO

[†] *No longer commercially available. Use of EMI 9789Q is recommended whenever possible.*
[*] Corrugated window to increase red response.

The cold boxes of the 1 m and 0.5 m ESO are interchangeable. The other telescopes use cold boxes with different field lenses.

3.19.3 General references

- Carleton, N., 1974, *Astrophysics, vol. 12, Part A: Optical and Infrared,* (Academic Press)
- Golay, M., 1974, *Introduction to Astronomical Photometry,* (Dordrecht, Reidel)
- Harris, W.E., Fitzgerald, M.P. and Reed, B.C., 1981, *PASP* **93**, 507
- Lindgren, H., 1992, ESO Operating Manual # 16, *Photoelectric Photometers* (includes a detailed list of references)
- Olsen, E.H., 1983, Catalogue of four-colour uvby and Hβ photometry of A5 to G0 stars brighter than $8\overset{m}{.}3$

3.19.4 The 3.6 m standard photometer

Introduction

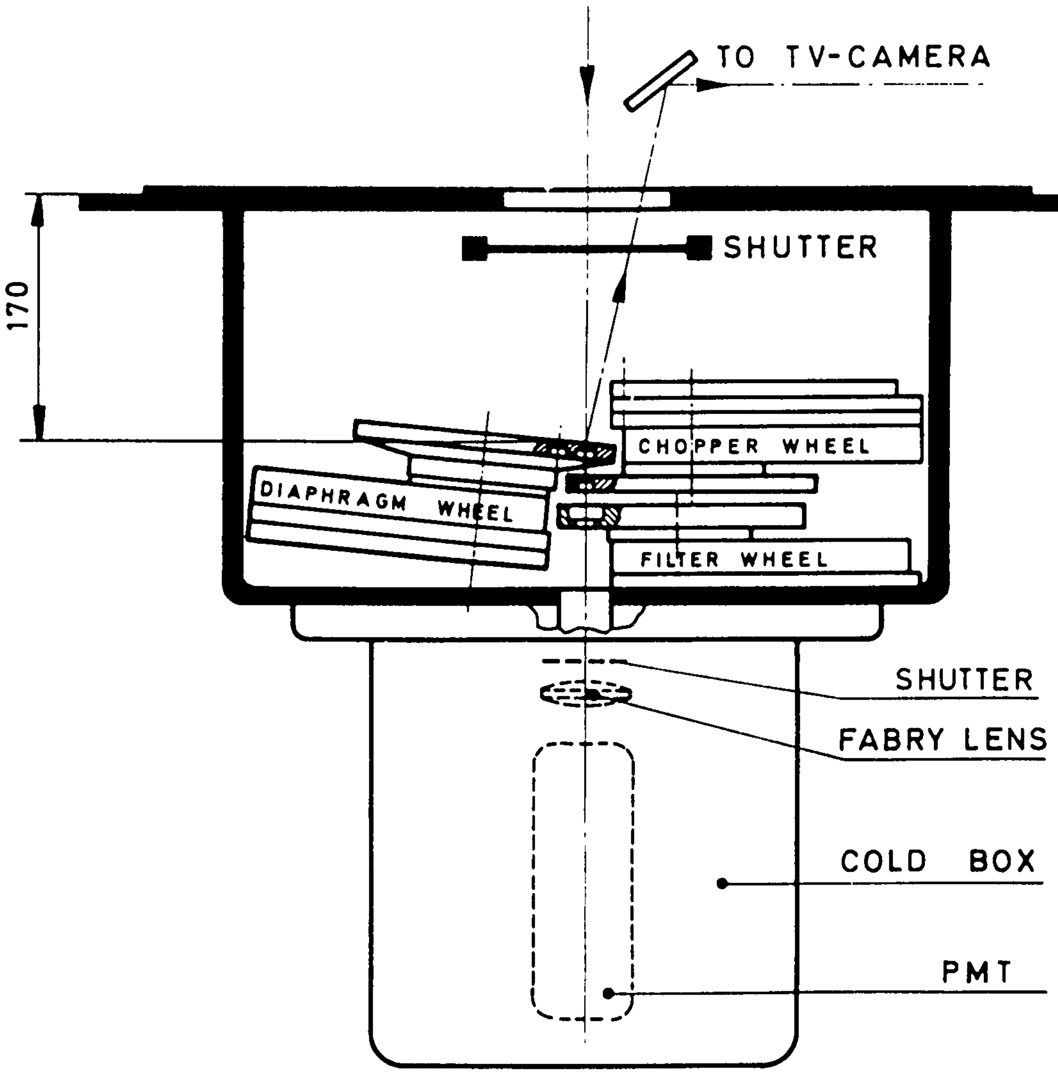


Figure 3.19: The 3.6 m standard photometer

The 3.6 m standard photometer was commissioned in 1981 and is a single channel photometer which is mounted at the Cassegrain focus. The layout of the photometer is illustrated in Fig. 3.19. The diaphragm wheel is slightly inclined to the image plane and its outer face is polished in order that the star field can be seen by reflection through the normal 3.6 m TV viewing system in the Cassegrain adapter (see Section 2.1.2). This has the added convenience that guiding can be carried out on field stars during the measurement. The standard *Products for Research* dry ice or Peltier (for Quantacon) cold boxes are used, and these have special combined Fabry lenses and entrance windows which reduce light losses. These cold boxes are not interchangeable with other photometers. The 3.6 m photometer is only available for fast photometry now.

Diaphragms

The diaphragms are double: 0 through 6 separated by 40 arcsecs, and 7 through 11 separated by 30 arcsecs. As the sky function is not implemented, only one diaphragm of each pair is used as in a normal single channel photometer.

Table 3.29: 3.6 m photometer: diaphragm sizes

Diaphragm No.	0/5	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. arcsec	4	7	10	15	22	30	

Diaphragm 6 is the target diaphragm used for centering the object. Note that centering of the telescope is carried out on the target diaphragm, with the shutter closed so that the photomultiplier is not damaged.

Filters

The filter wheel contains up to eight filters numbered 0 to 7, which can be positioned automatically. The filters are 1 inch (2.5 cm) in diameter and up to 10 mm 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). The standard positions of the filters are indicated in Table 3.30.

Photomultipliers

The list of photomultipliers available for the 3.6 m photometer is given in Table 3.28. The system uses standard pulse counting techniques.

Table 3.30: 3.6 m photometer: standard filter wheel positions

Position	Filter	ESO #
1	free	
2	U	283
3	B	275
4	V	276
5	R	277
6	I	278
7	closed	
0	closed	

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 take care of closing it when he/she is not making an integration.*

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 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 in 1.8 hours.

The present timing stability of the fast photometry system is about 2 parts in 10^{10}.

Magnitude limits

Table 3.31: 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

Typical count rates for a selection of stars are given in Table 3.31 for the UBVRI system using a Quantacon tube and a 15$''$ diaphragm. Stars brighter than V= 10^m should not be observed.

References

- Bessell, M.S., 1976, *PASP* 88, 557
- Cousins, A.W.J., 1973, *Mem. R. Astron. Soc.* 77, 223
- Lindgren, H., 1992, ESO Operating Manual # 16

3.19.5 The single channel photometer at the 1 m telescope

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. Field viewer.
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 field viewer has a field of view of 7 arcmin.

An image intensifier can be attached to the below diaphragm 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 3.32: 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	60.86	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 his/her own. In all cases, the visitor should inform ESO staff through the request for observing time which filters he/she intends to use. This is to ensure that no conflicts with other telescopes occur and that the filters are available.

When carrying out Strömgren, Johnson or UBV photometry, the following filter sequence is normally used (and is default in data acquisition and reduction programs):

Table 3.33: 1 m optical photometer: standard filter wheel positions

Position	Filter No.	Position	Filter No.
0	HβN 17	6	Closed
1	HβW 22	7	---
2	u 15	8	Closed
3	v 9	9	U 113
4	b 5	10	V 111
5	y 2	11	B 112

Consult ESO Operating Manual # 16 if a different choice of positions is made, and on-line magnitudes are required.

Telescope and photometer control

Both the telescope and the photometer are controlled from terminals in the dome. The telescope control system (TCS) and data acquisition system (DAS) are implemented on a HP 2100 and an HP 21MX computer with a 50 Mbyte disk. The TCS handles telescope pointing, telescope drive and coordinate precessing. The DAS controls the photometer setting and handles data and output devices. The DAS is linked to the TCS program.

The TCS has access to the CATALOG program.

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 (e.g. a minimum and maximum number of integrations), each of some integer number of seconds, or a mean deviation criterion (e.g. 0.5% accuracy). Then 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 reached, the photometer moves to the next filter.

Magnitude limits and on-line magnitudes

Objects should not be brighter than V= $7\overset{m}{.}0$ for UBV, V= 9^{m} for VRI, and V= $5\overset{m}{.}0$ for uvby photometry. *This is to avoid damage to the multipliers.* Stars down to V=17 mag can be seen and centered in the diaphragm under good seeing conditions. For faint objects an accuracy of $0\overset{m}{.}05$ at 16^{m} and $0\overset{m}{.}1$ at 17^{m} can be obtained (see e.g. Adam, 1978). Typical count rates with diaphragm # 5 (15 arcsec) are given in Tables 3.34 and 3.35.

Table 3.34: 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

Table 3.35: 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					(countss 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
sky			typical			25	30	45	55	140

3.19.6 The single channel photometer at the 0.5 m ESO telescope

Introduction

This photometer is mounted at the Cassegrain focus of the 0.5m ESO telescope. It is a conventional photometer consisting of the following components, given in the order that they are encountered along the optical path:

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

An image intensifier eyepiece is also available (ask the operations group or write it in the filter request form).

The system uses standard pulse counting techniques.

Viewfinder

The viewfinder has a field of 15 arcmin. It has an illuminated crosswire and five concentric rings centered on the field. These rings are separated by 1 arcmin. The field is reversed, and with the photometer mounted with the eyepieces on the west side, north is to the 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 3.36: 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 diameter and up to 10 mm thick. The VA should inform ESO staff through the request for observing time which filters he/she intends to use.

When carrying out Strömgren and Johnson photometries, the following filter sequence is normally used (and is default in data acquisition and reduction programs):

Table 3.37: 0.5 m ESO photometer: standard filter wheel positions

Position	Filter No.	Position	Filter No.
0	Hβ N 58	6	Dark
1	Hβ W 21	7	- - -
2	u 13	8	Dark
3	v 11	9	U 91
4	b 6	10	V 99
5	y 2	11	B 98

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 so that the photomultiplier with cold box is interchangeable. The observer may choose the photomultiplier most suitable for his/her programme from the available range of tubes (Table 4.4).

Telescope and photometer control

Both the telescope and the photometer are controlled from a terminal in the dome; the photometer can also be 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 precessing. 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 the 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. The observer can specify for each filter, integration limits, e.g. a minimum and maximum number of integrations each of some integer number of seconds, or a mean deviation stop criterion (e.g. 0.5% accuracy). The observer subsequently only initiates the observing sequence, which is 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 sequence. This mode is useful in studying rapidly varying stars. It also provides a convenient check on the quality of the night.

Magnitude limits

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 $\sim 15^m$ can be seen and centered in the diaphragm *under good seeing conditions.* Typical count rates for EMI 6256 with 21″ diaphragm are:

Table 3.38: 0.5 m ESO photometer: typical count rates for UBV system

	V	B-V	U-B	U	B	V
		magnitudes			c/s	
E7 – 89	6.09	−0.06	−0.25	81 K	233 K	48 K
E4 – 28	6.63	1.20	1.21	5420	55 K	33 K
E3 – 9	8.91	−0.04	−0.26	5880	17 K	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

Typical count rates in the UBVRI system using a Quantacon (RCA 31034) tube and a 21″ diaphragm are:

Table 3.39: 0.5 m ESO photometer: typical count rates for UBVRI system

	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

Chapter 4

Detectors and filters

4.1 Charge coupled devices – CCDs

4.1.1 Introduction

The main detector in use at present at La Silla, as throughout astronomy, are Charge Coupled Devices or CCDs. EFOSC, CASPEC, CES, ECHELEC, and the Boller and Chivens spectrographs are now equipped with CCDs. The direct imaging adapters at the 2.2 m, 1.5 m Danish, and 91 cm Dutch telescopes have CCDs, and the 3.5 m NTT uses CCD detectors in EMMI and SUSI. At present, there are 14 CCDs in normal use at La Silla and several in reserve.

In this section some of the basic properties of CCDs are discussed, the calibration of CCD data is briefly addressed, and the characteristics of all available CCDs are presented.

4.1.2 Basic properties of CCDs

A CCD is a semiconductor device consisting of an array of pixels which convert incident photons into electrons and trap these electrons in a potential well. The conversion factor or *quantum efficiency* is high ($\sim 50 - 85\%$) and the device is linear until near saturation of the pixels' potential wells.

At the end of an exposure, the CCD is read out by transferring the charge collected by each pixel to its neighbour and so on by using appropriately clocked voltages. Finally, each pixel is sequentially read out by an on-chip amplifier which produces an analogue signal proportional to each of the collected charges.

This signal is then converted into digital form and the numbers or ADUs are stored on disk or tape. The electronic digital image is now ready for the data reduction process, by which the useful astronomical data are extracted.

The read out process is destructive: *CCDs can only be read out once per exposure.*

All CCDs have a dark current which decreases with decreasing temperature and, therefore, all CCDs at La Silla are cooled with liquid N_2 to a temperature of between 140 K and 180 K. Typical dark currents are between 3 and 50 e^- hr^{-1} pix^{-1} at this temperature. Dark current is higher during the first 12 hours after switching on CCD electronics.

During exposures, the CCD is occasionally hit by high energy particles due to local radioactivity and cosmic rays. These "hits" show up as pixels with a high charge level. Typical rates are in the range 500 – 2000 hr^{-1} over the whole CCD. High resolution CCDs, which have smaller pixels, suffer fewer events per pixel. Typical exposure time limits before too many hits are collected are 1 to 6 hours, depending on the particular CCD and its environment. Median filtering or "lesser" image techniques are very effective at removing such events.

The CCD preamplifiers are pre-loaded with an electronic offset level of about 200 units — this is called the *bias* — and this has to be subtracted from all frames taken.

Some CCDs have poor charge transfer efficiency during the read-out process and these chips need a so-called preflash of about 80 – 100 e^-. This is done automatically during the exposure and can be enabled in the set-up of the CCD.

All CCDs suffer read-out noise (RON). This is a fixed noise which comes from the read-out preamplifier. Slow read-out gives a lower RON than fast read-out. Typical values are 5 to 50 e^- for the available CCDs.

Some CCDs have "cosmetics" defects which can be serious. Charge traps, bad or "hot" columns, and bad pixels are examples.

At La Silla there are four types of CCD in use:

a). Front illuminated Ford Aerospace (now LORAL) chips of 2048^2 pixels of 15 μm^2 with UV coating. Typical RON=8e^-.

b). Thinned, back illuminated, anti-reflection coated Tektronix chips with either 512^2 pixels of 27 μm^2, or 1024^2 pixels of 24 μm^2. Typical RON=9e^-.

c). Front illuminated, UV coated Thomson chips of 1024^2 pixels of 19 μm^2. Typical RON=5 e^-.

d). Thinned, back illuminated RCA chips with 320×512 $pixels^2$ of 30 μm^2 size, or 640×1024 $pixel^2$ of 15 μm^2. Typical RON=40 e^-.

Typical response curves are shown in Fig. 4.1.

Thinned chips show interference fringes, especially in the red (> 600 nm) which can reach 30 to 35% modulation levels.

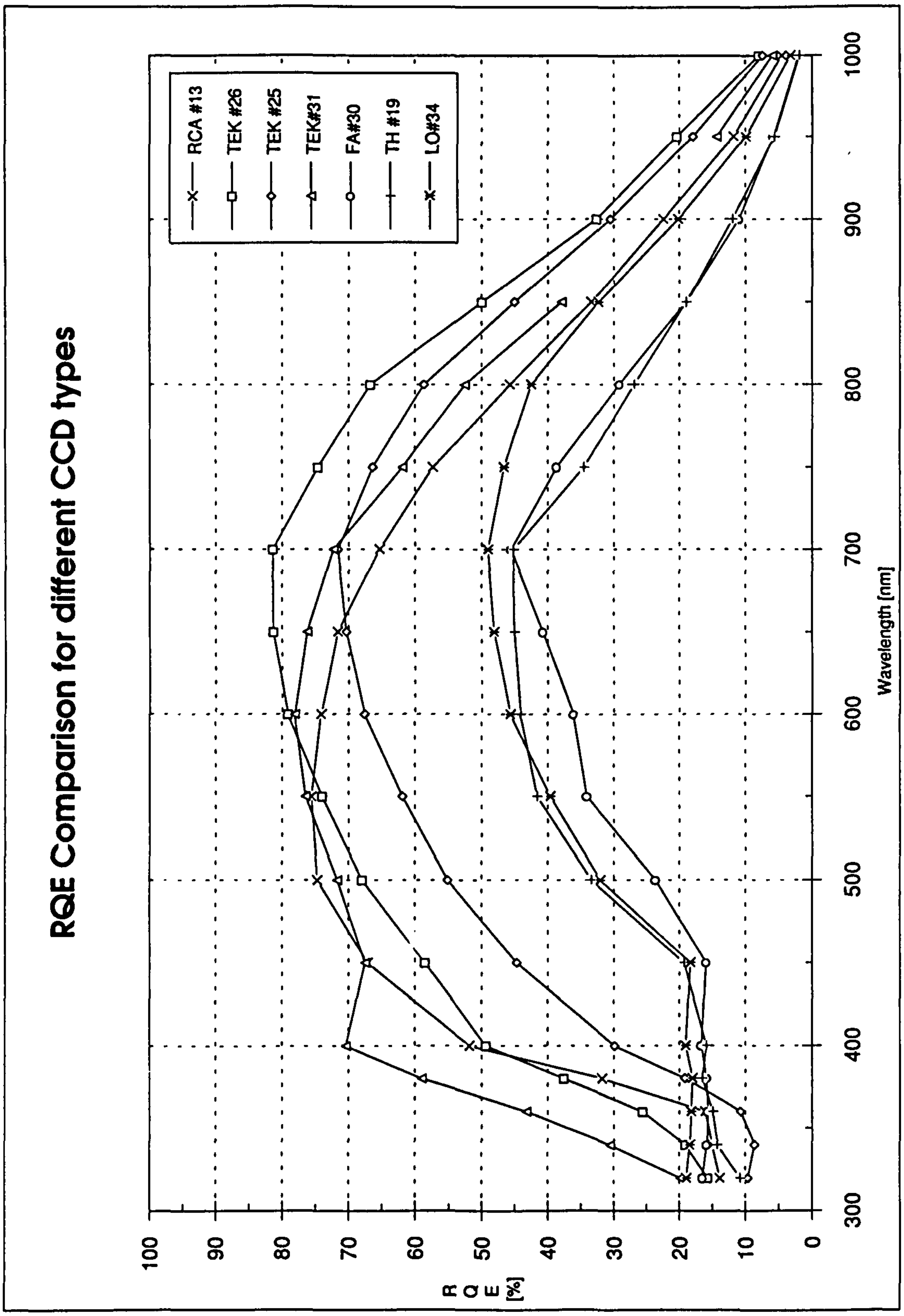


Figure 4.1: CCD: typical response curves for the various CCD types

4.1.3 Calibration

For a general reference on the calibration of CCD data reading the proceedings of the ASP Conference 23 "Astronomical Observing and Reduction Techniques" is recommended. A general discussion of the basic calibrations is given below.

The basic frames needed for all CCD work in addition to the science frames are the following:

1. Several bias frames.
2. Several flat fields.
3. Dark current frames.
4. Standard star frames for spectroscopy/spectrophotometry.
5. Wavelength calibration frames for spectroscopy.
6. Special calibration frames for e.g. polarimetry.

Bias

There are two possible ways to remove the bias from all frames. In both cases several — e.g. 3 groups of 5 — frames should be taken with an exposure time of 0 seconds and the shutter closed. Each group of 5 should be averaged to get 3 frames. Any cosmic rays recorded during the read-out process (this lasts up to 5 minutes for a high resolution chip) can be removed by taking the median of the 3 average frames.

The bias frame can then be subtracted from all frames, or the average pixel value of the whole frame can be used and this number ($\sim$ 200 units) subtracted from the frames. Which method is better depends on the quality of the bias frames, and must be determined for individual cases. In some chips, the bias level changes systematically from one side of the CCD to the other (e.g. away from the on-chip amplifier): here the scalar method cannot be used and a true bias frame has to be subtracted. Column arrays may be used to measure the S/N ratio.

Dark current

All CCDs produce electrons in the absence of light. This dark current is a thermal process and depends on the temperature of the chip. For this reason all CCDs used for astronomical purposes are cooled by liquid nitrogen (LN_2) to a temperature in the range 130–150K. At these temperatures the dark current is low: typically a few tens of electrons per pixel per hour for older CCDs, and only a few electrons for modern chips. The measured dark current values for all CCDs used at La Silla are listed in Table 4.1 of this manual.

To calibrate the dark current it is recommended to take dark exposures, that is exposures with the shutter closed and as little light in the dome as possible. The exposure times of these dark frames should be chosen to match those of the science frames taken. The reason for this is that there are possible non-linear effects in the behaviour of the dark current as a function of exposure time. The bias subtracted dark frames can then be subtracted from the science exposures. Any spatial structure in the dark current will then also be removed. For CCDs with extremely low dark currents, taking dark frames is usually unnecessary and only bias frames need to be taken.

Flat fields

The basic purpose of a flat field is to provide a map of the sensitivity variations over the particular CCD chip. This map depends on the wavelength of the incident light, the passband of the filters used, the exposure level, the spectral distribution of the light source used, and the CCD temperature. The best flats are obtained with a light source whose spectral energy distribution is matched to that of the science frame, whose exposure level is approximately equal to that of the science frame, and whose S/N level is significantly higher than that of the science exposure. The CCD parameters, especially the temperature, should be kept the same for flat fields and science frames.

In practice, these conditions can never be met exactly and a compromise has to be made.

Typical applied methods are:

1. **Direct imaging.**
   (a) Sky flats. By taking several exposures of the field, each with a small ($\sim 10''$) telescope offset, a "master flat" can be produced. Taking the median of several frames will remove the star images and a good flat will be obtained.

   Pro: energy distribution is the same.

   Con: expensive on "active" telescope time, cannot be used when background level varies (moon, etc).

   Also, "empty fields" can be used to take twilight flats. A list of these fields is available in the control room. These fields normally contain no objects brighter than V=20.

   (b) Dome flats with scattered daylight. Take several exposures on the inside of the dome — usually equipped with a reflective screen — with sun light entering through a door or hatch.

   Pro: colour temperature fairly well matched.

   Cons: brightness changes during exposures so it is difficult to set exposure time correctly.

   (c) Dome flat with quartz-halogen lamp. Take several exposures off dome screen illuminated by lamp.

   Pro: stable source; accurate exposure setting.

   Con: colour temperature too low ($\sim$2800 K) so for broad filters, especially in the red, fringes may *not* be fully corrected.

For narrow blue filters exposure times are very long since lamp is not emitting in the blue. For filters with red leaks, the leak can effectively be *stronger* than the main passband due to the red spectrum of the lamp.

(d) Flats from internal lamps. Take several exposures with an internal lamp illuminating the CCD.

Pros: stable source, accurate exposure setting.

Cons: as for (c) above. Also, since light path through instrument is different, fringing correction is sometimes even worse than method (c).

2. **Spectroscopy.**

Here, only lamps should be used since the sky produces spectral lines which would contaminate the spectra.

(a) Dome flats with quartz-halogen lamp. Take several exposures off the dome screen.

Pro: stable source, path through spectrograph similar to that of science frames.

Cons: for blue range, need long exposures giving heavily overexposed red spectral range. Need wide range of exposure levels. Could use filters to reduce red light — also in science frames.

(b) Flats with internal lamp. Take several exposures with internal quartz lamp.

Pro: stable source.

Cons: as in previous case, but also the path of the light tends to be different from that of science frames.

In summary, for direct imaging some form of sky flats tend to be the best, for spectroscopy dome flats with a lamp. For very narrow band imaging the spectral distribution of the flat field light source is not so important.

Note that taking some spectra on the twilight sky can be useful to check for any vignetting along the slit, especially in long slit mode.

4.1.4 Available CCDs at La Silla

The following pages provide information about the individual CCDs now available at La Silla.

Data on the physical properties of the chips, their read-out noise, charge transfer efficiency, gain, dark current, full well capacity and blemishes are given, as are their quantum efficiency curves as a function of wavelength.

References

- Sinclaire, P., 1992, CCD detectors available at La Silla

Table 4.1: *CCDs at La Silla per January 1992*

CCD # normally used at	**Chip type**	**Number of pixels pixel size (μm)**	**Nominal gain (e^-/ADU)**	**RON (rms e^-)**	**RQE (%) @ 350, peak, 900 (nm)**	**Dark ($e^-.pix^{-1}.hr^{-1}$) @ temp.**	**linear up to: (e^-)**	**Full well capacity (e^-)**	**Cosmetics and remarks**
8 2.2m	RCA SID 006 EX	1024×640 15	4.1	28	75 13 @ 20 540	6 @ 140K	100K	150K	Col 41 dead, many small col. offsets, non linear below 4000e$^-$. Lower sensivity in area: X 243 → X 244; Y 327 → Y 389. FF good.
9 CES	RCA SID 006 EX	1024×640 15	4.9	32	75 15 @ 24 530	2·5 @ 140K	100K	150K	Hot col. 480; col. offsets.
13 1.52m Echelec	RCA SID 006 EX	1024×640 15	3.7	65	75 15 @ 24 550	39 @ 140K	100K	150K	Hot col. 517. Hot pix. 501, 480.
18 Not used	Thomson 31156 Coated	1024×1024 19	2 *	5	45 17 @ 12 650	<1 @ 140K	30K	175K	Residual images. Very clean.
19 EFOSC2	Thomson 31156 Coated	1024×1024 19	2 *	4	43 15 @ 12 650	<2 @ 140K	100K	100K	Residual images. Very clean.
24 1.52 B&C	FORD 2048L	2048×2048 15	3 *	10	45 1 @ 12 700	2 @ 165K	85K	105K	Hot col. 1189 Trap col. 1191; 14 traps: 4 big, 10 small. 30 pix pattern repeat from masking. V. low residual image.
25 SUSI	TEK TK1024M	1024×1024 24	3·3	12	71 10 @ 30 700	3 @ 165K	180K (but see note)	220K	Warm col. X937, dark col. X936. Trap X1043. Start at Y300. Weak thinning pattern. CCD will not function under manufacturers specified bias voltages. Nonlinear at 1% level under actual bias voltages.
26 EFOSC1	TEK TK512CB	512×512 27	4	9	81 20 @ 32 700	8 @ 172K	400K	480K	Small dark spots, prob. dust in AR coating. Some slight residual image.
28 Danish 1.5m	TEK 1024M AR Coated	1024×1024 24	3·6	8	70 10 @ 38 700	12 @ 176K	160K	240K	V. good chip. 8 small traps. Uniformity 3% at $\lambda > 500$nm, 9% at $\lambda = 320$nm.

Table 4.1: *CCDs at La Silla per January 1992 (cont.)*

CCD # normally Used at	**Chip type**	**Number of pixels pixel size (μm)**	**Nominal gain (e$^-$/ADU)**	**RON (rms e$^-$)**	**RQE (%) @ 350, peak, 900 (nm)**	**Dark (e$^-$.pix^{-1}.hr^{-1}) @ temp.**	**Linear up to: (e$^-$)**	**Full well capacity (e$^-$)**	**Cosmetics and remarks**
29 Optopus	TEK 512CB Thinned coated	512x512 27	3·6	7·7	71 28 @ 28 650	10 @ 183K	265K	291K	Not yet installed
30 CAT long	FA 2048L UV coated	2048x2048 15	2·9	13	46 15 @ 12 700	4·5 @ 183K	87K	103K	CTE drops above 75 Ke.
31 EMMI blue	TEK 1024 AB Thinned coated MPP	1024x1024 24	3·3	8	76 40 @ 27 600	8 @ 166K	150K	~200K	Upper half of CCD has lower full well capacity than lower.
32 Caspec	TK 512 CB Thinned coated MPP	512x512 27	4·4	11	76 45 @ 31 650	10 @ 162K	320K	360K	
33 Dutch	TK 512 CB Thinned coated	512x512 27	4·1	10	80 45 @ 31 600	6·5 @ 162K	580K	690K	Cosmetically excellent
34 EMMI R	LORAL 2048 UV coated	2048x2048 15	1·5	7	48 48 @ 20 700	2 @ 161K	~75K	187K	Over 200 charge traps.

*For CCD's marked with an *, the gain in fast readout is 4 times that given in the table (slow mode). RON is also somewhat higher in fast mode.*

4.2 Focusing

Detection efficiency for faint point sources depends critically on image diameters. For a case where the object is not undersampled, efficiency goes as the square of image diameter. At a given site, and with a given telescope/instrument combination, the crucial operation is the focusing of the telescope. The observer has to take several parameters into account: thermal expansion and flexure of the telescope, filter optical thickness. Since the time that has to be spent on focusing represents an effective loss of observing time, anything that can be done to shorten this time will improve the observing efficiency.

For the two mirror systems considered here; that is a telescope used at its Cassegrain or Nasmyth focus (the 3^{rd} mirror is flat), we have:

$$\delta F = -(1+\gamma^2) * \delta S$$

where δF is the focal plane movement relative to the primary mirror, δS is the movement of the secondary mirror and γ is the telescope factor, which is the ratio between the focal ratio of the telescope and that of its primary mirror. Table 4.2 lists the γ factor for all telescopes at La Silla. Clearly, this implies that since the telescope changes its length with temperature, the focus will be critically dependent on the temperature. In general, the temperature will drop quite fast at the beginning of the night, just after the dome has been opened, and then stay constant or nearly so. Focusing repeatedly during this critical period is therefore of great importance. Note that due to the fairly long thermal time constants of large telescopes, it is sometimes not possible to give a focus equation that is accurate for rapid changes of temperature.

At La Silla, there are two types of instruments to focus:

a. Those with parallel beams (focal reducer type), and

b. those with a convergent beam (imaging and spectroscopy).

The focusing procedure is different for these types of instrument.

4.2.1 Focusing parallel beam instruments: EFOSC1 and 2, EMMI RILD mode

A single exposure is taken through the filter to be used or, for spectroscopy, without filter. A device called the focal analyzer or focus wedge is used for this exposure, placed in the grism wheel of the instrument. The focus wedge produces two horizontally separated images on the CCD for each star in the field. When perfectly in focus the images will fall on the same row of the chip. The amount of defocus is related to the amount of vertical separation between the images, and the calibration of the wedge yields the number of encoder steps to be applied to the telescope focus to obtain the correct focus. In practice, once the image has been obtained, a batch is run on the computer. The batch will ask the

Table 4.2: $(1+\gamma^2)$ factors for the La Silla telescopes

Telescope	Focus	$(1+\gamma^2)$
3.6 m	Cassegrain f/8	8.1
	IR f/35	137
NTT	Nasmyth	26
2.2 m	Cassegrain f/8	8.1
	IR f/35	137
1.54 Danish	Cassegrain	6.9
1.52 m	Cassegrain	12.1
	Coudé	45.4
CAT/CES	f32.3	117
1 m	Cassegrain	11
0.91 m Dutch	Cassegrain	16.3
0.50 m ESO	Cassegrain	19.4

Note that the factor $(1+\gamma^2)$ gives the ratio of the speed of movement of the focal plane and the secondary mirror.

observer to identify a number of stars interactively on the screen, and will calculate the mean value for the offset to be applied to the telescope focus. It is recommended to set the focus approximately to the correct value, either by using the focus equation or by eye. When running the focus batch on images that are severely out of focus, a second image should be taken after the focus has been corrected to check on the results, and make a final fine adjustment of the focus. After having focused the telescope in this manner, it is a good idea to take a direct image with the same filter, but without the focal analyzer in the beam to check on the seeing. All seeing measurements should be recorded in the appropriate book in the control room. If there is a systematic difference in the X and Y diameters of the stellar images, this could indicate an optical problem or a defocus.

4.2.2 With a convergent beam

This method is somewhat more time consuming, since more than one exposure has to be taken.

Using a special focus exposure definition, a multi-exposure frame can be obtained. The frame will consist of a number of sub-exposures, typically 8 or so, each of, say 30 seconds. Between each sub-exposure the telescope is offset by about 10 arcsec and the focus changed by a fixed amount. A series of images is then produced on one CCD frame with a range of focus values, chosen to start out of focus, passing through the correct focus and becoming out of focus on the other side of the focal plane. A curve can then be fitted to the FWHM diameters of the images, from which the optimum focus value can be determined by finding the minimum of this curve. In practice, the fitting is done by running a batch, identifying the star images and setting the encoder value provided by the batch on the telescope focus. This method can also be used to focus spectrographs and to calibrate the focus wedge in parallel beam instruments. For spectrographs, the exposures are taken through the slit, and the width of the stellar profiles is measured.

4.2.3 Focus equations for telescopes

Each telescope has its own peculiar focus versus temperature behaviour. The basic movement is simply due to the expansion of steel with increasing temperature, which amounts to 1.5×10^{-5} per °C. By taking the telescope factor discussed and listed above into account, the focus equation can be constructed.

Most telescopes also show a focus variation with zenith distance. This is usually a much smaller effect than the temperature variation, and is due to non-compensated flexure in the structure. Only at the 2.2m telescope is this term accurately known. It is shown below in the focus equation for that telescope.

Any filters introduced into the beam change the optical path length and thence the focus. In parallel-beam instruments the filters produce a small offset to the focus value. This is due to the fact that all filters show some power, and therefore change the effective focal length of the beam. The filter offsets to the focus have been determined for all standard filter sets, and are available in the control room of the telescope in question. For general filters, the observer has to determine the offset either by making another focus exposure or by calculating the offset from the data in the filter catalogue.

In convergent beams the focus changes mainly as the optical thickness of the particular filter. The mechanical thicknesses of all imaging filters have been measured and are listed in the filter catalogue. To obtain the optical thickness of a filter, the refractive index is taken into account as $s = d(n-1)/n$ where s is the optical thickness, d the mechanical thickness and n is the refractive index of the filter. The filters used at La Silla have $n = 1.533 \pm 0.030$ so that $s = d\,(0.348 \pm 0.013)$. This can produce significant focus offsets and it is always recommendable to make an independent focus determination. Only when the filter is known, optically as well as mechanically, can the calculation be trusted.

4.3 Photomultipliers

The following types of photomultiplier tubes (PMT) are available at La Silla for photometry.

The EMI types 9789QB and 9658, and RCA C31034A "Quantacon". These tubes are front illuminated. The RCA tube has a GaAs reflection photocathode, the EMI tubes have transmission cathodes.

The main properties of these PMTs are listed in Table 4.4.

Table 4.3: Focus equations for various telescopes at La Silla

3.6 m f/8	$F = C + 40T$
NTT	$F = C + 0.076T$
2.2m f/8	$F = C + 0.0045\sqrt{z} + 24.64s - 19T$
1.5D	$F = C - 57.67s + 17.5T$

Where F is focus in telescope encoder units, T is the temperature of the long telescope truss, z is the zenith distance in degrees, and s is the filter optical thickness in mm.

Table 4.4: Photomultipliers available on La Silla

Tube		*Cath.*	*Gain*	*Peak QE (%) at λ*		*Window*	*λ range (nm)*
C31034	RCA	GaAs	1×10^6	25	2800	fused silica	180 – 930
R943–02	Hamamatsu	GaAs	5×10^5	25	2800	fused silica	180 – 930
R928	Hamamatsu	S–20 E	1×10^7	25	2800	UV glass	200 – 930
9789Q	EMI	Bialkali	25×10^6	26	3500	quartz	170 – 650
9658R	EMI	S–20	0.6×10^6	25	4000	prismatic	300 – 900

Figure 4.2 shows typical sensitivity curves of these tubes.

For applications in which the highest sensitivity is necessary, especially in the red part of the spectrum, the GaAs tubes are most suitable. Note, however, that these tubes saturate at lower exposures than the multi alkali type tubes; GaAs tubes are suitable for photocounting applications up to $\sim 2 \times 10^5$ cts s^{-1}.

The other tubes can handle count rates of up to 10^6 cts s^{-1}.

4.4 Filters

About 650 broad and narrow band filters are available at La Silla which are listed in Table 4.5 in order of ascending wavelength.

Diameters lie between 25.4 mm (1 inch) and 65 mm and there are special high quality filters for direct imaging purposes. These are indicated with the letter I.

At La Silla, when specifying a filter to be installed in an instrument, please also use the ESO number, which is also given in Table 4.5.

In this manual the transmission curves of the filters are not given; these curves, measured with the Bruins double beam spectrophotometer, can be found in the ESO filter inventory, a copy of which is kept in the ESO libraries (Garching and La Silla).

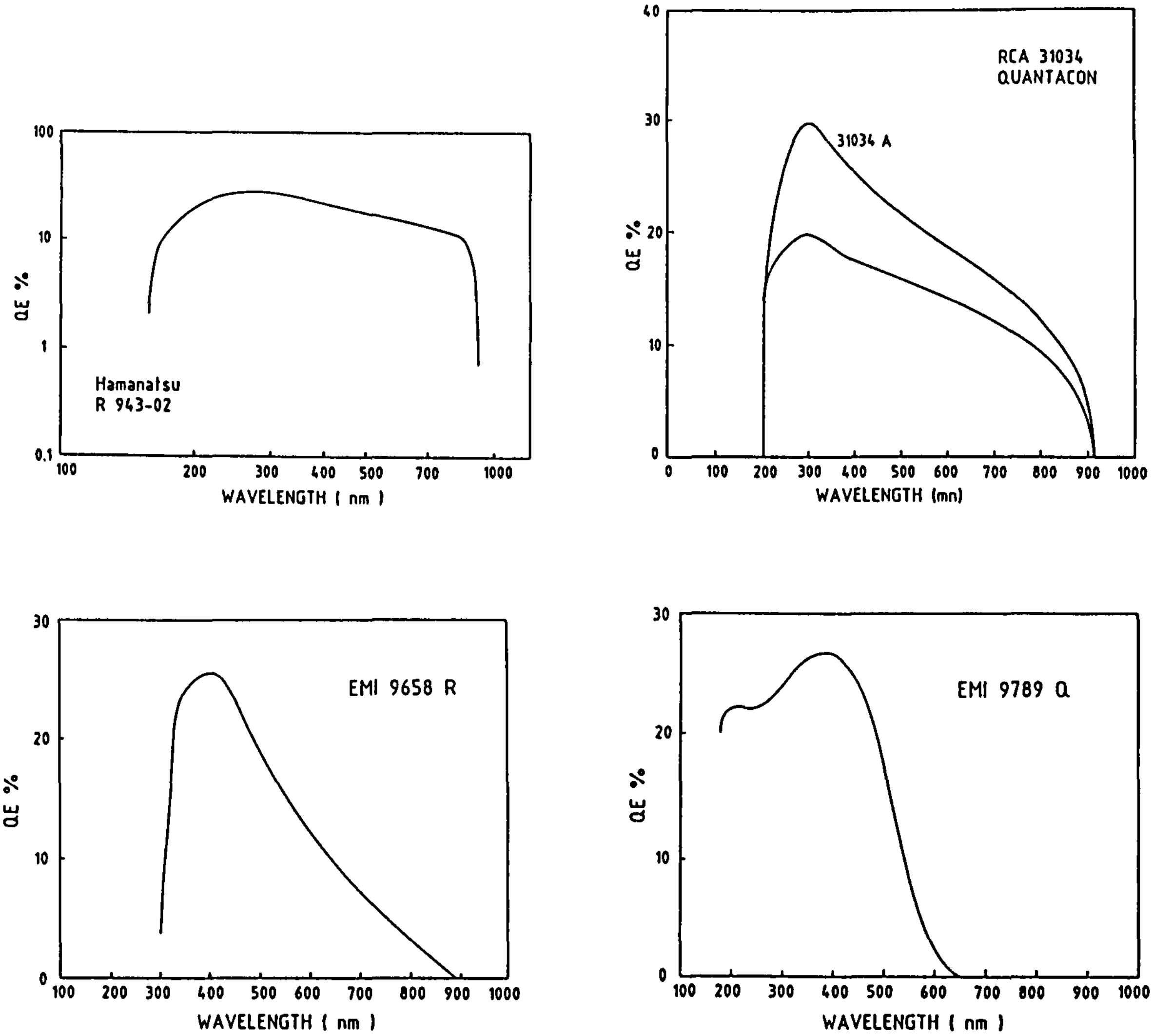


Figure 4.2: Photomultipliers: sensitivity curves

The *red leak* column gives the wavelength starting from which red leak has been detected. BL means blue leak.

The optical thickness and the size of the filters are given in millimetres.

In MIDAS, using the `CREATE/GUI FILTERS` commands the complete filter data base can be accessed (a printed version of the ESO Image Quality Filters Catalogue is available upon request). Plots of transmission curves, files with the values used for the plots, and various other filter parameters can be easily obtained.

All imaging quality filters are now being remeasured out to 1.3μm to obtain a better assessment of the red leak.

References

Gilliotte, A., 1991, Imaging Quality Filters Catalogue

Table 4.5: Filters available on La Silla

Filter #	*Features* Q-S*	*Peak wavelength Å*	*Band-width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick-ness (mm)*	*Comments*
117	C	3244	1449	88	0.88	25.40	2.7	GG-495 Schott
91	N-C	3247	1369	87	2.80	25.40	5.0	Photometry
241	S	3257	853	75	1.43	25.40	3.9	
658	I-C	3310	751	71	2.24	85.00	6.0	EUV UG11+UG5
104	S	3344	65	31	2.92	25.40	8.1	
711	I-C	3385	325	36		60.00		
227	C	3388	457	43	0.71	25.40	4.7	
15	C	3428	396	42	2.10	25.40	8.8	
647	I-C	3440	83	42	2.24	85.00	6.0	NeV
16	S	3441	396	43	2.10	25.40	8.8	
106	S	3453	873	79	2.15	25.40	5.9	
715	I-C	3490	350	34		60.00		
310	N-C	3492	322	43	0.95	25.40	9.9	Photometry
322	N-C	3493	321	44	2.15	25.40	8.9	Photometry
343	N-C	3493	318	41	1.64	25.00	8.8	UG11(8MM)+WG345(1MM)
328	N-C	3495	319	43	2.11	25.40	8.9	Photometry
160	C	3495	94	23	3.16	25.40	4.4	
334	N-C	3496	321	43	2.14	25.40	8.9	Photometry
316	N-C	3499	320	43	2.12	25.40	8.9	Photometry
101	S	3513	347	30	1.45	24.50	8.8	
173	C	3517	29	9	2.00	51.00	5.5	
562	N-S	3519	372	58	2.24	25.00	3.1	Cousins
221	C	3520	291	27	0.39	25.40	9.1	
567	N-S	3525	372	58	2.24	25.00	3.1	Cousins
220	C	3525	291	25	0.39	25.40	9.1	
218	C	3526	293	27	0.39	25.40	9.1	
219	C	3526	292	27	0.39	25.40	9.1	
217	C	3528	295	28	0.39	25.40	9.1	
66	C	3532	105	25	2.14	25.40	7.2	
67	C	3534	103	24	2.14	25.40	7.3	
236	S	3543	394	47	1.33	24.00	5.0	
232	S	3547	396	48	2.18	24.00	5.0	
222	C	3566	259	15	0.39	25.40	9.1	
105	S	3573	90	40	2.42	25.40	6.8	
189	C	3584	626	72	0.71	25.00	2.0	
444	N-C	3592	513	68	2.84	60.00	8.0	Free diameter 48mm
418	I-C	3592	513	68	2.84	60.00	8.0	Old
454	I-C	3593	513	67	2.84	60.00	8.0	
113	N-C	3605	591	64	0.71	25.40	2.0	Photometry
631	I-C	3606	537	67	2.24	60.00	6.0	Basic set
131	S	3606	815	79	0.36	51.00	1.0	UG-1 Schott
630	I-C	3607	535	68	2.24	60.00	6.0	Basic set
634	I-C	3608	535	68	2.24	60.00	6.0	Basic set
633	I-C	3609	537	68	2.24	60.00	6.0	Basic set
103	S	3610	480	57	1.43	25.40	4.1	
100	S	3610	477	57	1.45	25.40	4.0	
283	N-C	3615	752	78	2.07	25.40	6.1	Photometry CuSO4+UG2
602	I-C	3617	542	69	2.24	85.00	7.0	U

⋆ Quality : I=image; N=non-image
Shape : S=quare; C=circular

Filter #	*Features* Q–S*	*Peak wavelength Å*	*Band–width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick–ness (mm)*	*Comments*
640	I-C	3618	532	68	2.24	60.00	6.0	
624	N-C	3619	753	8053	2.24	25.50	6.0	Photometry CuSO4+UG2
109	S	3622	591	6491	0.74	25.00	2.0	
449	I-C	3623	515	6715	2.84	60.00	8.0	
632	I-C	3631	535	6635	2.24	60.00	6.0	Basic set
572	N-C	3638	631	7131	2.24	60.00	4.2	CuSO4 Liq.
537	N-C	3646	45	2945	1.86	51.00	8.9	
571	N-C	3647	686	7486	2.24	60.00	7.0	CuSO4 Liq.
517	N-C	3655	81	2881	2.22	38.00	6.1	
161	C	3663	103	2903	3.16	25.40	5.3	
644	I-C	3700	0	99	2.24	85.00	6.0	GG375
556	N-C	3703	485	5585	2.24	25.00	3.1	Photometry BG39+UG2
48	C	3719	34	934	2.76	51.00	9.6	
557	N-C	3720	490	5490	2.24	24.60	3.1	BG39+UG2
648	I-C	3725	67	3767	2.24	85.00	6.0	OII
555	N-C	3733	486	4486	2.24	25.00	3.1	BG39+UG2
1301	I-C	3736	43	1643	2.24	65.50	7.0	GASCOIGNE
102	S	3747	100	3500	2.58	25.40	7.2	
134	S	3775	0	89	0.40	51.00	0.9	GG-435 Schott
513	I-C	3776	99	3199	2.14	60.00	6.1	
649	I-C	3792	67	4467	2.24	85.00	6.0	OII/5000
505	N-S	3811	3570	8470	1.00	50.00	3.0	
514	I-C	3849	87	5287	2.21	60.00	6.3	
650	I-C	3863	70	4470	2.24	85.00	6.0	OII/10000
676	I-C	3877	19	2719	2.24	59.00	9.0	Wampler LMC
518	N-C	3900	47	3447	2.22	38.00	6.1	
233	S	3938	463	4963	3.34	24.00	9.0	
515	I-C	3941	108	5708	2.22	60.00	6.3	
504	N-S	3949	0	89	1.10	50.00	3.0	
237	S	3949	450	4850	3.60	24.00	9.1	
651	I-C	3950	75	4175	2.24	85.00	6.0	0II/15000
487	N-C	3971	646	6746	1.80	50.00	6.9	80nm set
216	C	3975	1417	8217	0.39	25.30	1.1	
130	S	3981	1447	8447	0.73	51.00	2.0	BG-12 Schott
215	C	3999	1439	8239	0.39	25.40	1.1	
516	I-C	4003	99	5899	2.22	60.00	6.1	
228	C	4029	652	7052	0.71	25.40	9.3	
480	N-C	4073	337	6137	1.80	50.00	6.9	40nm set
605	I-C	4074	1084	6784	2.24	85.00	7.0	B Blue path
519	N-C	4074	75	4575	2.17	38.00	6.1	
97	S	4085	210	5110	1.60	25.40	4.5	
716	I-C	4095	200	5960		60.00		Basic set
712	I-C	4100	200	5970		60.00		Basic set
9	S	4104	165	5865	2.10	25.40	6.0	Lot of scratches
527	N-C	4118	175	5375	2.06	25.40	5.9	Photometry
604	I-C	4128	939	7039	2.24	85.00	7.0	B for focus wedge
603	I-C	4136	935	6735	2.24	85.00	7.0	B
158	C	4138	149	5749	2.58	25.40	7.2	
159	C	4138	159	5159	3.16	25.40	8.8	
156	C	4138	165	6165	2.63	25.40	7.3	
532	N-C	4144	173	5173	2.06	25.40	5.9	Photometry

⋆ Quality : I=image; N=non-image
Shape : S=square; C=circular

Filter #	Features* Q-S	Peak wavelength Å	Band-width Å	Peak Transmission (%)	Optical thickness	Size (mm)	Thick-ness (mm)	Comments
157	C	4147	165	6465	2.95	25.40	8.2	Reflectometer
121	C	4154	112	4812	0.82	25.40	4.2	
49	C	4179	57	4957	2.62	51.00	7.5	
116	C	4183	98	4598	3.53	25.40	9.8	
39	C	4189	36	3236	3.04	25.00	8.7	
329	N-C	4190	191	4591	2.13	25.40	6.0	Photometry
317	N-C	4193	192	4592	2.14	25.40	6.1	Photometry
335	N-C	4193	192	4592	2.13	25.40	6.2	Photometry
323	N-C	4193	192	4592	2.13	25.40	6.1	Photometry
311	N-C	4195	192	4592	2.13	25.40	6.1	Photometry
539	I-C	4215	10	1510	2.27	59.10	6.6	
211	C	4229	1021	7321	1.13	25.30	3.1	
209	C	4234	1020	7420	1.13	25.40	3.1	
54	C	4236	45	4145	2.98	25.40	8.8	
53	C	4237	47	3947	3.00	25.40	8.9	
573	I-C	4247	77	6477	2.24	60.00	7.6	
210	C	4249	1027	7327	1.11	25.40	3.0	
112	N-C	4262	1078	7778	2.31	25.40	6.7	Photometry
115	C	4271	84	6484	3.41	25.40	9.7	
520	N-C	4274	71	5771	2.15	38.00	5.9	
196	C	4285	1028	6928	1.85	25.40	5.2	BG-12+GG-385+BG-38 S
162	C	4286	70	5970	3.53	25.40	10.1	
728	I-C	4295	60	5230		60.00		
214	C	4316	1222	7722	1.73	25.40	4.9	
212	C	4316	1224	7824	1.72	25.40	4.9	
198	C	4317	982	6582	1.89	25.40	5.2	BG-12+ GG-385+ BG-38
199	C	4317	999	6599	1.87	25.40	5.2	BG-12+ GG-385+ BG-38
118	C	4318	1230	7830	0.88	25.40	9.0	
213	C	4324	1227	7827	1.73	25.40	4.9	
265	N-C	4339	25	3725	2.17	25.20	6.2	
62	C	4340	30	4730	3.00	25.40	8.8	
61	C	4340	29	4629	3.00	25.40	8.9	
174	C	4348	15	3115	3.59	51.00	10.3	
197	C	4349	957	6257	1.88	25.40	5.2	BG-12+ GG-385+ BG-38
729	I-C	4366	63	5230		60.00		
38	C	4363	13	3013	2.48	25.00	7.4	
445	I-C	4366	1017	6717	2.82	60.00	8.0	Free diameter 48mm
98	N	4370	1060	8860	1.60	25.40	4.5	Photometry
256	C	4371	999	5799	1.50	51.00	4.1	
639	I-C	4381	1012	5712	2.24	60.00	6.0	
92	S	4382	1082	8982	2.80	25.40	7.0	
419	I-C	4384	1019	6619	2.82	60.00	8.0	Basic set
284	N-C	4400	984	5484	1.65	25.40	4.5	Photometry
293	N-C	4404	980	5380	1.66	25.00	4.6	Stand. set
240	S	4408	947	5747	1.87	23.00	5.1	
494	N-S	4410	0	89	1.11	50.00	3.1	LWP set
450	I-C	4412	1025	6625	2.82	60.00	8.0	Basic set
279	N-C	4415	974	5474	1.67	25.10	4.6	Photometry
724	I-C	4415	1825	8090		60.00		Basic set
566	N-S	4420	1001	5501	2.24	25.00	3.1	Cousins
289	N-C	4424	980	5480	1.70	25.40	4.7	Photometry
561	N-S	4430	997	5597	2.24	25.00	3.1	Cousins

⋆ Quality : I=image; N=non-image
Shape : S=square; C=circular

Filter #	*Features★ Q–S*	*Peak wavelength Å*	*Band–width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick–ness (mm)*	*Comments*
275	N-C	4434	984	5484	1.65	25.40	4.6	Photometry
301	N-C	4434	969	5469	1.69	25.40	4.7	
52	C	4437	53	5153	3.04	25.40	8.4	
305	N-C	4437	976	5476	1.69	25.40	4.7	
51	C	4440	52	5252	2.62	25.40	8.4	
455	I-C	4441	1007	6807	2.82	60.00	8.0	
510	I-C	4467	56	8056	2.59	60.00	7.2	
1405	N-C	4468	110	5110	3.47	65.60	7.2	Gascoigne
587	I-C	4474	48	5448	2.24	85.00	7.0	HeI
625	I-C	4513	105	7405	2.24	60.00	6.0	Azzopardi request
583	I-C	4515	941	5541	2.24	60.00	7.6	Basic set
481	N-C	4520	338	6338	1.72	60.00	6.9	40nm set
488	N-C	4520	657	6557	1.71	50.00	6.9	80nm set
720	I-C	4537	52	6500		60.00		
114	C	4543	114	6314	3.35	25.40	9.5	
552	I-C	4553	945	5645	2.24	60.00	8.3	Basic set
626	I-C	4586	109	7909	2.24	60.00	6.0	Azzopardi request
59	C	4597	53	6153	1.42	25.40	4.1	
60	C	4601	52	6352	1.42	25.40	4.1	
163	C	4617	61	6161	3.55	25.40	10.0	
722	I-C	4632	230	5000		60.00		
324	N-C	4637	167	5867	2.22	25.40	6.3	Photometry
499	N-S	4637	909	8509	1.12	50.00	3.2	SWP set
96	S	4641	165	4565	2.77	25.40	7.8	
330	N-C	4641	167	5967	2.22	25.40	6.2	Photometry
336	N-C	4644	167	5967	2.22	25.40	6.2	Photometry
318	N-C	4649	168	5868	2.15	25.40	6.1	Photometry
164	C	4650	40	6240	3.10	25.40	8.8	
312	N-C	4650	167	5967	2.15	25.40	6.1	Photometry
713	I-C	4655	1500	7900		60.00		
717	I-C	4660	175	7680		60.00		
122	C	4663	138	5738	0.82	25.40	5.4	
1406	N-C	4670	98	4798	3.34	65.60	7.2	Gascoigne
512	I-C	4680	59	8159	2.58	60.00	7.3	
165	C	4684	44	6744	3.15	25.40	8.9	
677	I-C	4691	9	51	2.24	59.00	9.2	Wampler LMC
627	I-C	4692	114	7814	2.24	60.00	6.0	Azzopardi request
88	C	4694	12	4712	2.83	25.40	8.2	
533	N-C	4697	168	6668	1.83	25.40	5.2	Photometry
588	I-C	4697	66	7266	2.24	85.00	7.0	HeII
652	I-C	4698	73	6573	2.24	85.00	6.0	HeII
1401	N-C	4698	23	5223	3.52	65.00	7.0	Gascoigne
153	C	4699	199	5599	3.00	25.40	8.6	
152	C	4700	183	6183	2.13	25.40	6.1	
154	C	4703	186	6586	2.40	25.40	6.8	
528	N-C	4703	168	6868	1.82	25.40	5.2	Photometry
155	C	4704	200	5200	2.86	25.40	8.1	
135	S	4720	0	90	0.74	51.00	2.9	GG-475 Schott
166	C	4734	78	6178	3.20	25.40	9.1	
545	I-C	4739	149	6849	2.24	60.00	6.3	
730	I-C	4746	47	7630		60.00		
231	C	4758	115	3515	2.18	25.00	6.2	
175	I-C	4772	46	5520	2.52	51.00		

★ Quality : I=image; N=non-image
Shape : S=square; C=circular

Filter #	*Features* Q-S*	*Peak wavelength Å*	*Band-width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick-ness (mm)*	*Comments*
37	C	4778	45	4645	2.85	25.00	7.9	
1402	N-C	4793	70	7670	3.48	65.00	7.0	Gascoigne
86	C	4798	13	5413	3.20	25.40	9.2	
500	N-S	4816	1388	8988	1.05	50.00	3.1	SWP set
24	S	4824	155	7055	2.09	25.60	6.0	
521	N-C	4829	62	6562	2.17	38.00	6.1	
143	C	4836	162	6362	2.72	25.40	7.8	
140	C	4836	162	6862	2.50	25.00	7.2	
142	C	4836	167	5567	2.94	25.40	8.4	
339	N-C	4843	142	6342	2.14	25.40	6.0	Photometry
141	C	4843	167	6467	2.68	25.20	7.6	
321	N-C	4844	142	6342	2.15	25.40	5.9	Photometry
333	N-C	4844	142	6242	2.14	25.40	6.0	Photometry
315	N-C	4844	143	6143	2.12	25.40	7.0	Photometry
536	N-C	4845	160	7160	1.86	25.40	5.3	Photometry
531	N-C	4846	160	7260	1.86	25.40	5.3	Photometry
327	N-C	4846	144	6244	2.11	25.40	5.9	Photometry
580	N-C	4851	64	6764	2.24	25.40	7.6	SOFT Coat.
574	N-C	4851	65	6865	2.24	25.40	7.6	SOFT Coat.
577	N-C	4851	65	6865	2.24	25.40	7.6	SOFT Coat.
1404	N-C	4856	744	6944	0.54	65.00	7.2	Gascoigne
147	C	4858	31	5731	2.76	25.40	7.9	
546	I-C	4860	66	6766	2.24	60.00	6.3	
145	C	4860	31	5131	2.70	25.40	7.7	
19	S	4861	29	5029	2.51	25.60	7.2	Lot of scratches
535	N-C	4861	28	6228	1.83	25.40	5.2	Photometry
58	C	4862	39	6339	1.50	25.40	4.3	Phot.
530	N-C	4863	27	6527	1.83	25.40	5.2	Photometry
176	C	4863	18	5918	2.91	51.00	8.1	
264	N-C	4863	20	4120	1.95	25.40	5.5	
1403	N-C	4864	40	4740	0.54	65.00	7.2	Gascoigne
320	N-C	4865	26	5326	2.10	25.40	5.9	Photometry
338	N-C	4866	27	5327	2.11	25.40	5.9	Photometry
146	C	4866	32	5432	2.28	25.40	6.5	
57	C	4866	39	6439	1.52	25.40	4.4	
332	N-C	4867	26	5326	2.11	25.40	5.9	Photometry
326	N-C	4867	27	5327	2.11	25.40	5.9	Photometry
25	C	4868	32	5532	2.24	25.00	6.5	
314	N-C	4868	27	5127	2.12	25.40	6.1	Photometry
719	I-C	4893	50	7800		60.00		
22	S	4894	191	7191	2.06	25.60	6.0	Broken
21	S	4894	193	6893	2.06	25.40	5.9	
238	C	4910	657	6857	1.37	25.20	3.9	
234	C	4913	655	6855	1.33	25.40	3.8	
548	I-C	4920	53	6753	2.24	60.00	6.3	
495	N-S	4945	0	90	1.10	50.00	3.0	LWP set
538	N-C	4956	29	6829	3.46	51.00	9.6	
549	I-C	4956	61	6661	2.24	60.00	6.3	
489	N-C	4961	766	7866	1.66	50.00	6.9	80nm set
502	N-S	4965	2163	9063	1.05	50.00	3.1	SWP set

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Filter #	*Features* Q–S*	*Peak wavelength Å*	*Band–width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick–ness (mm)*	*Comments*
369	I-C	4980	139	6340	1.90	60.00		
550	I-C	4982	58	6458	2.24	60.00	6.3	
575	N-C	4993	74	5974	2.24	25.40	7.6	SOFT Coat.
628	I-C	4997	1029	9029	2.24	60.00	6.0	Azzopardi request
589	I-C	4997	57	6357	2.24	85.00	7.0	OIII
268	N-C	4998	58	5158	1.70	25.40	4.8	
169	C	4999	105	3505	1.51	24.70	4.3	
581	N-C	5000	74	5774	2.24	25.40	7.6	SOFT Coat.
170	C	5004	105	3505	1.44	24.70	4.0	
688	I-C	5005	57	7557	2.24	60.00	7.0	Basic set
427	I-C	5005	66	7466	2.15	60.00	6.2	Basic set
578	N-C	5005	74	5974	2.24	25.40	7.6	SOFT Coat.
177	C	5005	22	6122	2.91	51.00	8.8	No data
1407	N-C	5005	86	6786	3.46	65.70	7.2	Gascoigne
183	C	5007	26	6026	3.24	51.00	9.2	
36	C	5008	19	5019	2.12	25.40	6.1	
368	I-C	5008	56	6880	2.95	60.00		
686	I-C	5008	59	7159	2.24	60.00	6.9	Basic set
360	N-C	5009	56	7056	1.95	25.40	5.5	
678	I-C	5013	8	38	2.24	59.00	9.0	Wampler LMC
687	I-C	5015	55	7455	2.24	60.00	6.9	Basic set
689	I-C	5017	57	7457	2.24	60.00	7.0	Basic set
690	I-C	5017	57	7357	2.24	60.00	6.9	Basic set
119	C	5018	0	86	0.82	25.00	2.3	GG-495 Schott
1501	I-C	5023	20	6020	3.46	65.00	7.2	Gascoigne
428	I-C	5045	130	7430	2.10	60.00	6.2	
590	I-C	5052	63	5063	2.24	85.00	7.0	OIII/3000
370	N-C	5054	54	7054	1.90	60.00	5.6	
361	N-C	5056	53	7253	1.98	25.40	5.6	
725	I-C	5066	57	8020		60.00		OIII r/6000
471	N-C	5097	818	8818	1.08	60.00	3.0	
525	I-C	5098	102	7902	3.18	51.00	9.0	
463	I-S	5100	813	8813	1.08	51.00	3.1	Basic set
340	N-C	5102	192	8292	1.60	25.40	4.5	
591	I-C	5102	61	7161	2.24	85.00	7.0	OIII/6000
459	I-C	5102	820	8720	1.08	60.00	3.1	Basic set
423	I-C	5102	805	8905	1.05	60.00	3.1	
475	N-S	5103	814	8814	1.08	51.00	3.0	
362	N-C	5105	64	7164	1.92	25.40	5.5	
371	N-C	5106	64	6964	1.90	60.00	5.6	
430	I-C	5117	56	7256	2.12	60.00	6.2	
467	N-C	5118	814	8814	1.08	60.00	3.0	
612	I-C	5121	759	8159	2.24	60.00	6.0	Basic set
616	I-C	5122	775	8175	2.24	60.00	6.0	Basic set
620	I-C	5126	760	8060	2.24	60.00	6.0	Basic set
522	N-C	5129	98	7198	2.10	38.00	6.0	
372	N-C	5153	63	7063	1.90	60.00	5.6	
592	I-C	5154	65	6865	2.24	85.00	7.0	OIII/9000
167	C	5155	135	8235	3.55	25.50	10.1	

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Filter #	Features* Q–S	Peak wavelength Å	Band–width Å	Peak Transmission (%)	Optical thickness	Size (mm)	Thick–ness (mm)	Comments
363	N-C	5156	59	7159	1.94	25.40	5.6	
726	I-C	5159	62	7760		60.00		
349	N-S	5161	1091	8491	2.15	51.00	6.2	Old set
593	I-C	5192	65	6565	2.24	85.00	7.0	OIII/12000
229	C	5202	200	5800	2.05	25.00	5.8	
373	N-C	5204	60	6760	1.90	60.00	5.5	
99	N-S	5205	210	9110	1.60	25.40	4.0	Photometry
643	I-C	5205	2734	9834	2.24	85.00	6.0	BG38
364	N-C	5207	59	6859	1.94	25.40	5.5	
432	I-C	5210	60	7460	2.16	60.00	6.3	
302	N-C	5215	1044	7944	1.28	25.40	3.5	
294	N-C	5216	1044	7844	1.23	25.20	3.4	Stand. set
290	N-C	5227	1040	7840	1.28	25.00	3.6	Photometry
172	C	5236	123	4623	1.40	25.40	4.0	
111	N-S	5238	0	92	1.43	25.40	4.0	Photometry
594	I-C	5239	65	6765	2.24	85.00	7.0	OIII/15000
285	N-C	5241	1047	7847	1.21	25.40	3.4	Photometry
298	N-C	5241	1038	7938	1.29	25.40	3.6	Photometry
280	N-C	5241	1060	7960	1.19	25.10	3.3	Photometry
276	N-C	5243	1045	7845	1.24	25.40	3.5	Photometry
451	I-C	5252	1167	8767	2.78	60.00	8.0	Basic set
365	N-C	5253	58	7158	1.95	25.40	5.6	
641	I-C	5260	1130	8030	2.24	60.00	6.0	
201	C	5262	1314	8514	1.84	25.40	5.2	
433	I-C	5264	55	7055	2.14	60.00	6.2	
203	C	5264	1311	8411	1.84	25.40	5.2	
446	I-C	5269	1168	8768	2.78	60.00	8.0	Free diameter 48mm
456	I-C	5270	1170	8770	2.78	60.00	8.0	
374	N-C	5272	58	7158	1.90	60.00	5.6	
526	N-C	5284	165	7665	3.14	51.00	8.8	
202	C	5287	1309	8409	1.85	25.40	5.2	
606	I-C	5289	1035	9035	2.24	85.00	7.0	V
257	C	5290	1154	7954	1.12	51.00	3.1	
584	I-C	5290	1131	8731	2.24	60.00	7.6	Basic set
420	I-C	5293	1169	8969	2.78	60.00	8.0	Basic set
87	C	5297	11	5111	3.28	25.40	9.4	
645	I-C	5300	0	99	2.24	85.00	6.0	OG530
375	N-C	5301	65	6865	1.92	60.00	5.5	
366	N-C	5302	61	6261	1.98	25.40	5.5	
1503	N-C	5303	30	4530	3.41	65.00	6.3	Gascoigne
679	I-C	5309	9	55	2.24	59.00	9.0	Wampler LMC
434	I-C	5313	55	7555	2.16	60.00	6.3	
560	N-S	5320	1049	7749	2.24	25.00	3.1	Cousins
565	N-S	5320	1044	7744	2.24	25.00	3.1	Cousins
56	C	5320	88	5788	2.98	25.40	8.8	
247	S	5323	1104	8104	1.05	25.00	3.0	
553	I-C	5325	1132	8732	2.24	60.00	8.0	Basic set
242	S	5325	1052	7652	1.41	25.40	3.9	
435	I-C	5348	66	7366	2.16	60.00	6.2	

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Filter #	*Features* Q–S*	*Peak wavelength Å*	*Band-width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick-ness (mm)*	*Comments*
367	N-C	5353	70	6670	1.95	25.40	5.5	
376	I-C	5354	65	6990	1.75	60.00		
35	C	5388	49	5549	2.27	25.00	6.5	
178	C	5390	39	6339	2.13	51.00	6.1	
1504	N-C	5395	76	4776	3.41	65.00	7.8	Gascoigne
125	C	5396	217	5917	0.82	25.40	5.4	
71	C	5401	718	5718	2.19	25.40	6.3	
68	C	5409	735	6035	2.27	25.40	6.5	
345	N-S	5419	1122	9222	0.35	51.00	1.0	Old set
133		5420	0	90	0.40	51.00	2.0	OG-550 Schott
331	N-C	5422	213	6313	2.17	25.40	6.1	Photometry
319	N-C	5422	214	6214	2.14	25.40	6.1	Photometry
325	N-C	5424	213	6313	2.17	25.40	6.2	Photometry
313	N-C	5426	214	6314	2.10	25.40	6.1	Photometry
337	N-C	5426	213	6313	2.17	25.40	6.1	Photometry
70	C	5433	710	5510	2.25	25.40	6.4	
168	C	5435	226	7726	3.45	25.40	9.7	
718	I-C	5445	175	7920		60.00		
534	N-C	5450	219	7219	2.02	25.40	5.8	Photometry
69	C	5475	768	6168	2.27	25.40	6.4	
151	C	5477	254	6754	2.49	25.40	7.1	
150	C	5481	259	6359	2.48	25.30	7.0	
483	N-C	5494	395	6795	1.71	50.00	6.9	40nm set
149	C	5499	246	7446	2.43	25.20	6.9	
4	S	5518	227	8127	2.31	25.40	6.7	
3	S	5524	232	7932	2.31	25.40	6.6	
529	N-C	5533	221	7321	2.02	25.20	5.8	Photometry
490	N-C	5591	744	7644	1.86	50.00	6.9	80nm set
270	N-C	5605	62	6262	1.94	25.20	5.5	
230	C	5681	140	3740	2.06	25.00	5.9	
84	C	5693	11	5811	3.14	25.40	9.1	
680	I-C	5728	8	35	2.24	59.00	9.0	Wampler LMC
34	C	5755	20	6320	2.81	25.40	8.1	
85	C	5810	12	5712	3.20	25.40	9.2	
194	C	5811	406	8506	2.04	25.40	5.7	
204	C	5832	1719	8019	1.39	25.40	4.0	
497	N-S	5850	0	89	1.13	50.00	3.0	LWP set
207	C	5851	1717	8117	1.41	25.40	4.0	
206	C	5863	1706	8206	1.44	25.40	4.1	
205	C	5865	1696	8196	1.44	25.50	4.1	
26	C	5876	21	5421	2.80	25.40	8.1	
179	C	5879	20	6920	2.79	51.00	7.8	
681	I-C	5883	9	38	2.24	59.00	8.7	Wampler LMC
267	N-C	5899	56	5356	4.52	25.30	4.8	
564	N-S	5902	1476	7776	2.24	25.00	3.1	Cousins
1502	N-C	5904	45	6845	1.95	65.00	6.3	Gascoigne
307	N-C	5908	1228	7128	1.78	25.40	5.1	
248	S	5920	1652	7952	1.42	25.40	4.0	
559	N-S	5929	1471	7871	2.24	25.00	3.1	Cousins
299	N-C	5933	1241	7141	1.76	25.40	5.0	Photometry

⋆ Quality : I=image; N=non-image
Shape : S=square; C=circular

Filter #	Features* Q–S	Peak wavelength Å	Band-width Å	Peak Transmission (%)	Optical thickness	Size (mm)	Thick-ness (mm)	Comments
277	N-C	5936	1224	7024	1.80	25.40	5.2	Photometry
303	N-C	5943	1202	7102	1.78	25.40	5.1	
286	N-C	5944	1218	7118	2.82	25.40	5.1	Photometry
585	I-C	5949	1654	8654	2.24	60.00	7.6	Basic set
295	N-C	5950	1212	7012	1.78	25.40	5.1	Stand. set
642	I-C	5954	1656	8656	2.24	60.00	6.0	
253	S	5958	1654	7954	1.43	24.00	4.0	
281	N-C	5958	1203	7103	1.79	25.40	5.1	Photometry
291	N-C	5965	1212	7112	1.77	25.00	5.0	Photometry
258	C	5968	1607	7807	1.44	51.00	4.1	
608	I-C	5975	1497	8597	2.24	85.00	7.0	R
554	I-C	5983	1666	8666	2.24	60.00	8.0	Basic set
421	I-C	5994	1638	8538	2.70	60.00	8.0	Basic set
243	S	5996	1631	7931	1.75	25.00	4.9	
457	I-C	6002	1638	8538	2.72	60.00	7.9	
452	I-C	6004	1640	8440	2.72	60.00	8.0	Basic set
447	I-C	6011	1632	8432	2.72	60.00	7.9	Free diameter 48mm
484	N-C	6011	357	7057	1.76	50.00	6.9	40nm set
344	N-S	6026	260	8260	1.50	51.00	4.4	
342	N-C	6095	431	8231	1.64	51.00	4.6	
83	C	6095	11	5011	3.14	25.40	9.1	
491	N-C	6162	816	7416	1.83	50.00	6.9	80nm set
136	S	6225	0	91	0.74	50.00	2.0	RG-630 Schott
33	C	6249	24	5424	2.82	25.40	7.8	
47	I-C	6250	24	5610	2.76	51.00		
75	C	6285	1049	6949	1.35	25.40	3.9	
498	N-S	6290	0	88	1.16	50.00	3.0	LWP set
46	I-C	6296	10	3250	2.66	51.00		
74	C	6305	1044	6944	1.37	25.40	3.9	
682	I-C	6308	9	65	2.24	59.00	9.0	Wampler LMC
184	C	6378	1793	8393	3.24	25.60	6.8	
185	C	6394	1833	8233	3.24	25.40	6.8	
186	C	6413	1832	8332	2.39	25.50	6.8	
485	N-C	6448	335	6335	1.73	50.00	6.9	40nm set
1601	N-C	6449	61	7461	3.46	65.00	7.8	Gascoigne
65	C	6466	153	5853	2.14	25.40	6.2	
385	I-S	6467	72	8372	2.09	51.00	6.0	Hα set
64	C	6470	152	5752	2.14	25.40	6.2	
386	I-S	6503	72	7972	2.14	51.00	6.1	HP note: do not use
437	I-C	6503	142	6342	2.16	60.00	6.2	
378	N-C	6536	169	6369	1.92	60.00	5.5	
1609	I-C	6545	106	5406	3.56	65.00	6.4	Gascoigne
346	I-C	6546	901	9630	1.10	51.00		Old set
387	I-S	6546	81	8681	2.14	51.00	6.1	Basic set
596	I-C	6547	73	5373	2.24	85.00	7.0	HA1
436	I-C	6548	62	7062	2.20	60.00	6.3	
691	I-C	6550	60	5960	2.24	60.00	7.0	Basic set
693	I-C	6550	61	5961	2.24	60.00	7.0	Basic set
692	I-C	6552	60	5860	2.24	60.00	7.1	Basic set

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Shape : S=square; C=circular

Filter #	*Features* Q–S*	*Peak wavelength Å*	*Band–width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick–ness (mm)*	*Comments*
654	I-C	6554	33	3733	2.24	85.00	6.0	Hα
263	N-C	6554	22	4922	1.92	25.40	5.6	
579	N-C	6556	71	5171	2.24	25.40	7.6	Soft Coat.
629	I-C	6556	115	9315	2.24	60.00	6.0	Azzopardi request
354	N-C	6557	69	6469	1.91	25.40	5.4	
377	N-C	6557	76	5976	1.92	60.00	5.6	
582	N-C	6559	71	5271	2.24	25.40	7.6	Soft Coat.
576	N-C	6560	72	5272	2.24	25.40	7.6	Soft Coat.
674	I-C	6561	12	6012	2.24	60.00	6.0	ESO# 42 replacement
28	S	6561	12	5712	2.80	25.40	7.9	
272	N-C	6562	48	7848	1.63	25.40	4.7	
683	I-C	6570	10	6610	2.24	59.00	9.0	Wampler LMC
1604	N-C	6572	39	5439	3.56	65.00	5.6	Gascoigne
81	S	6572	20	4820	2.36	51.00	7.0	
271	N-C	6573	166	8366	1.62	25.40	4.7	
568	N-C	6574	72	7572	2.24	51.00	7.0	
1610	N-C	6576	55	5355	1.33	64.70	3.4	Gascoigne
30	C	6577	10	4510	2.82	25.00	8.3	
1602	N-C	6579	20	4920	3.40	65.00	7.8	Gascoigne
694	I-C	6580	61	5561	2.24	60.00	7.0	Basic set
653	I-C	6581	32	5532	2.24	85.00	6.0	NII
63	S	6583	20	5020	2.00	51.00	5.9	
93	C	6584	23	4323	2.10	25.40	6.1	
595	I-C	6587	73	5373	2.24	85.00	7.0	NII
492	N-C	6590	789	7389	1.85	50.00	6.9	80nm set
684	I-C	6591	10	6310	2.24	59.00	9.0	Wampler LMC
1603	N-C	6593	36	5536	1.98	65.00	5.6	Gascoigne
379	N-C	6615	68	5768	1.89	60.00	5.4	
353	N-C	6615	69	5769	1.94	25.40	5.5	
597	I-C	6620	66	6266	2.24	85.00	7.0	HAl/3000
569	N-C	6629	75	8475	2.24	51.00	7.0	
438	I-C	6632	69	6669	2.16	60.00	6.2	
697	I-C	6635	61	5661	2.24	60.00	7.1	Basic set
613	I-C	6639	813	8313	2.24	60.00	6.0	Basic set
389	I-S	6641	79	8379	2.14	51.00	6.1	Basic set
698	I-C	6641	60	5360	2.24	60.00	6.9	Basic set
621	I-C	6642	812	8412	2.24	60.00	6.0	Basic set
273	N-S	6645	0	90	0.97	24.00	2.8	RG-665 Schott
696	I-C	6654	61	5661	2.24	60.00	7.1	Basic set
695	I-C	6656	62	6262	2.24	60.00	7.0	Basic set
137	S	6657	0	91	0.74	50.00	2.1	RG-665 Schott
1605	N-C	6660	114	6114	3.59	65.00	9.9	Gascoigne
598	I-C	6665	66	5966	2.24	85.00	7.0	HAl/6000
390	I-S	6678	80	8880	2.14	51.00	6.1	Hα set
439	I-C	6680	82	5782	2.17	60.00	6.1	
617	I-C	6695	836	8336	2.24	60.00	6.0	Basic set
655	I-C	6695	75	5375	2.24	85.00	6.0	SII
261	N-C	6702	14	4514	2.17	25.40	6.4	
380	N-C	6704	73	6773	1.89	60.00	5.4	

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Filter #	Features* Q–S	Peak wavelength Å	Band-width Å	Peak Transmission (%)	Optical thickness	Size (mm)	Thick-ness (mm)	Comments
355	N-C	6704	74	6774	1.89	25.40	5.4	
701	I-C	6711	64	5464	2.24	60.00	6.9	Basic set
702	I-C	6717	62	5662	2.24	60.00	7.0	Basic set
675	I-C	6722	30	8630	2.24	60.00	6.8	Basic set
80	S	6725	19	4519	1.92	51.00	5.6	
699	I-C	6726	58	5258	2.24	60.00	6.9	Basic set
570	N-C	6727	69	8069	2.24	51.00	7.0	
700	I-C	6728	59	6159	2.24	60.00	7.1	Basic set
239	S	6728	647	9247	1.37	25.20	3.8	
509	N-C	6729	13	5113	2.04	60.00	6.0	
1607	I-C	6735	25	5825	3.51	65.00	6.4	Gascoigne
391	I-S	6742	85	8985	2.14	51.00	6.1	Basic set
1606	I-C	6748	39	6339	2.36	65.00	6.4	Gascoigne
392	I-S	6748	82	8182	2.14	51.00	6.1	Hα set
356	N-C	6750	76	6076	1.95	25.40	5.6	
599	I-C	6752	69	5069	2.24	85.00	7.0	HAl/9000
381	N-C	6753	76	5976	1.89	60.00	5.5	
1608	I-C	6763	26	6826	3.56	65.00	6.4	Gascoigne
440	I-C	6775	70	6570	2.17	60.00	6.2	
600	I-C	6804	71	5571	2.24	85.00	7.0	HAl/12000
393	I-S	6809	85	8385	2.16	51.00	6.1	Hα set
441	I-C	6822	73	6573	2.18	60.00	6.2	
382	N-C	6828	82	5482	1.89	60.00	5.5	
357	N-C	6832	82	5982	1.90	25.40	5.4	
523	N-C	6859	85	7985	2.10	38.00	6.0	
394	I-S	6861	83	8683	2.13	51.00	6.0	Hα set
460	I-C	6865	1112	8412	1.14	60.00	3.1	Basic set
601	I-C	6879	73	5573	2.24	85.00	7.0	HAl/15000
395	I-S	6891	87	8287	2.12	51.00	6.0	Hα set
350	N-S	6898	1023	9423	1.15	51.00	3.1	Old set
472	N-C	6898	1061	8661	1.12	60.00	3.1	
468	N-C	6907	1040	8740	1.12	60.00	3.0	
464	I-S	6916	1081	8381	1.12	51.00	3.1	Basic set
45	C	6939	32	6632	1.57	51.00	4.5	
442	I-C	6939	64	6364	2.18	60.00	6.2	
358	N-C	6944	74	5974	1.95	25.40	5.6	
32	C	6947	27	4827	2.82	25.00	7.9	
383	I-C	6950	73	5950	1.88	60.00		
486	N-C	6950	370	7370	1.74	50.00	6.9	40nm set
396	I-S	6957	77	8677	2.16	51.00	6.1	Hα set
493	N-C	6986	975	7575	1.58	50.00	6.9	80nm set
397	I-S	6992	90	8290	2.14	51.00	6.1	Hα set
359	N-C	7023	57	6757	1.92	25.40	5.5	
384	N-C	7025	58	6658	1.90	60.00	5.5	
443	I-C	7027	64	6264	2.18	60.00	6.1	
138	S	7035	0	90	1.07	50.00	2.0	RG-715 Schott
398	I-S	7060	76	7776	2.13	51.00	6.1	Hα set
524	N-C	7115	222	8122	2.05	38.00	5.9	
399	I-S	7123	80	7880	2.14	51.00	6.1	Hα set

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Filter #	Features* Q-S	Peak wavelength Å	Band-width Å	Peak Transmission (%)	Optical thickness	Size (mm)	Thick-ness (mm)	Comments
400	I-S	7136	77	7377	2.14	51.00	6.1	Hα set
401	I-S	7184	71	7871	2.17	51.00	6.1	Hα set
402	I-S	7240	78	8078	2.17	51.00	6.1	Hα set
403	I-C	7271	77	9140		60.00		
586	N-C	7296	18	5318	2.24	50.70	7.0	Ghost
31	C	7321	28	4828	2.86	25.00	8.3	
44	C	7323	28	6228	2.68	51.00	7.8	
404	I-S	7331	73	8273	2.16	51.00	6.1	HP note: do not use
405	I-S	7348	86	7886	2.17	51.00	6.1	Hα set
406	I-S	7436	78	8478	2.18	51.00	6.1	Hα set
110	S	7465	508	2008	1.10	25.40	3.0	
108	S	7466	513	2013	1.10	25.40	3.0	
407	I-S	7478	81	8381	2.21	51.00	6.2	Hα set
292	N-C	7519	3002	9402	1.06	25.00	3.0	Photometry RG9
408	I-S	7528	81	8481	2.21	51.00	6.1	Hα set
618	I-C	7579	1255	8355	2.24	60.00	6.0	Basic Set
614	I-C	7579	1283	8483	2.24	60.00	6.0	Basic Set
409	I-S	7580	79	8179	2.20	51.00	6.0	Hα set
410	N-S	7621	83	8383	2.10	51.00	6.1	HP note: do not use
622	I-C	7651	1365	8465	2.24	60.00	6.0	Basic Set
411	I-S	7678	84	8384	2.17	51.00	6.0	Hα set
733	I-C	7685	1325	9560		60.00		
260	C	7695	16	5116	0.74	25.20	6.8	
182	C	7726	20	6220	2.79	51.00	6.0	
412	I-S	7739	76	7576	2.20	51.00	6.1	Hα set
732	I-C	7760	1475	960		60.00		
413	N-S	7775	90	8290	2.20	51.00	6.1	Hα set
129	C	7799	0	93	0.84	25.40	2.3	
458	N-S	7800	3518	9018	2.72	50.00	1.8	
107	S	7801	1910	6710	2.15	25.40	6.0	
259	C	7815	3398	9098	0.74	50.00	2.0	RG-9 Schott
127	C	7817	0	90	0.86	25.40	2.3	RG-780 Schott
414	I-S	7821	90	7990	2.20	51.00	6.1	Hα set
308	N-C	7841	3115	8915	0.95	25.40	2.9	RG9
287	N-C	7847	3063	9263	1.09	25.40	3.0	Photometry RG9
254	S	7861	3453	9153	0.68	24.60	1.9	RG-9 Schott
296	N-C	7861	3097	8997	0.91	25.10	3.0	RG9
128	C	7864	0	93	0.86	25.40	2.3	
415	I-S	7880	88	7988	2.20	51.00	6.1	Hα set
278	N-C	7883	3117	8917	0.95	25.00	2.9	Photometry RG9
304	N-C	7899	3117	8917	1.05	25.40	3.0	RG9
416	I-S	7922	89	7689	2.20	51.00	6.1	Hα set
563	N-S	7944	3428	9328	2.24	25.00	3.1	Cousins
282	N-C	7945	3113	8913	0.93	25.00	3.0	Photometry RG9
610	I-C	7956	1221	9921	2.24	85.00	7.0	I
244	S	8000	3447	9047	0.70	25.20	1.9	RG-9 Schott
351	N-S	8004	2023	9223	1.09	51.00	3.1	old set
300	N-C	8058	3105	8905	1.04	25.40	3.0	Photometry RG9
29	C	8117	48	5048	2.80	25.40	9.5	
43	C	8125	42	5442	3.04	51.00	7.3	
76	C	8137	1708	7108	1.35	25.40	4.7	

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Filter #	*Features* Q-S*	*Peak wavelength Å*	*Band-width Å*	*Peak Transmission (%)*	*Optical thickness*	*Size (mm)*	*Thick-ness (mm)*	*Comments*
558	N-S	8143	3462	9162	2.24	25.00	3.1	Cousins
77	C	8155	1701	7201	1.35	25.40	4.7	
78	C	8155	1701	7201	1.35	25.40	4.7	
79	C	8161	1703	7103	1.35	25.40	4.7	
477	N-S	8223	1353	8753	1.14	51.00	2.9	
223	C	8229	3574	8674	0.71	25.40	2.0	
465	I-S	8233	1390	8690	1.14	51.00	3.0	Basic set
469	N-C	8245	1396	8496	1.14	60.00	2.9	
473	N-C	8265	1426	8526	1.14	60.00	2.9	
347	N-S	8265	1885	8785	1.16	51.00	3.1	Old set
224	C	8267	3582	8682	0.71	25.40	2.0	RG-715 Schott
425	I-C	8291	1426	8526	1.10	60.00	3.0	
225	C	8295	3574	8674	0.71	25.40	2.0	RG-715 Schott
646	I-C	8306	1208	9908	2.24	85.00	6.0	RG715
226	C	8321	3572	8672	0.71	25.40	2.0	RG-715 Schott
470	N-C	8350	0	95	1.14	60.00	2.9	
348	N-S	8378	0	94	1.16	51.00	3.0	Old set
466	I-S	8400	0	95	1.14	51.00	3.1	Basic set
462	I-C	8400	0	93	1.14	60.00	3.1	Basic set
474	N-C	8400	0	94	1.14	60.00	3.1	
615	I-C	8400	0	98	2.24	60.00	6.0	Basic set
426	I-C	8400	0	92	1.10	60.00	3.0	
623	I-C	8400	0	97	2.24	60.00	6.0	Basic set
619	I-C	8428	0	98	2.24	60.00	6.0	Basic set
417	I-S	8500	0	94	2.20	51.00	3.1	
685	I-C	9075	19	3619	2.24	59.00	9.0	Wampler LMC
656	I-C	9125	193	9793	2.24	85.00	6.0	
657	I-C	9543	105	8805	2.24	85.00	6.0	SIII
1901	I-C	9547	93	9693	1.33	65.00	9.4	Gascoigne
11001	N-C	10310	106	8906	1.33	65.00	9.0	Gascoigne
269	N-C	10395	47	3847	1.70	25.10	8.1	
11002	I-C	10595	88	8788	1.33	65.00	9.3	Gascoigne
262	N-C	10829	21	6421	2.17	25.20	5.9	
181	C	10831	33	5933	2.79	51.00	7.7	
11003	N-C	10839	94	8794	1.33	65.00	9.0	Gascoigne

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