EUROPEAN SOUTHERN OBSERVATORY

OPERATING MANUAL

No. 6 – April 1986

OPTOPUS

MULTIPLE OBJECT SPECTROSCOPY AT THE CASSEGRAIN FOCUS OF THE 3.6 m TELESCOPE

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OF THE 3.6M TELESCOPE

G. LUND

ESO OPERATING MANUAL No. 6

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I INTRODUCTION

The fibre "Optopus" is designed to enable conventional use of the Boller and Chivens spectrograph to be extended to simultaneous spectroscopy of multiple or large extended objects. Despite field changeover times of the order of 20 minutes and a somewhat reduced transparency over that of the standard B&C configuration, a considerable overall gain in time and/or data volume can be achieved if the observer has many objects of interest within fields up to 33 arcminutes in diameter.

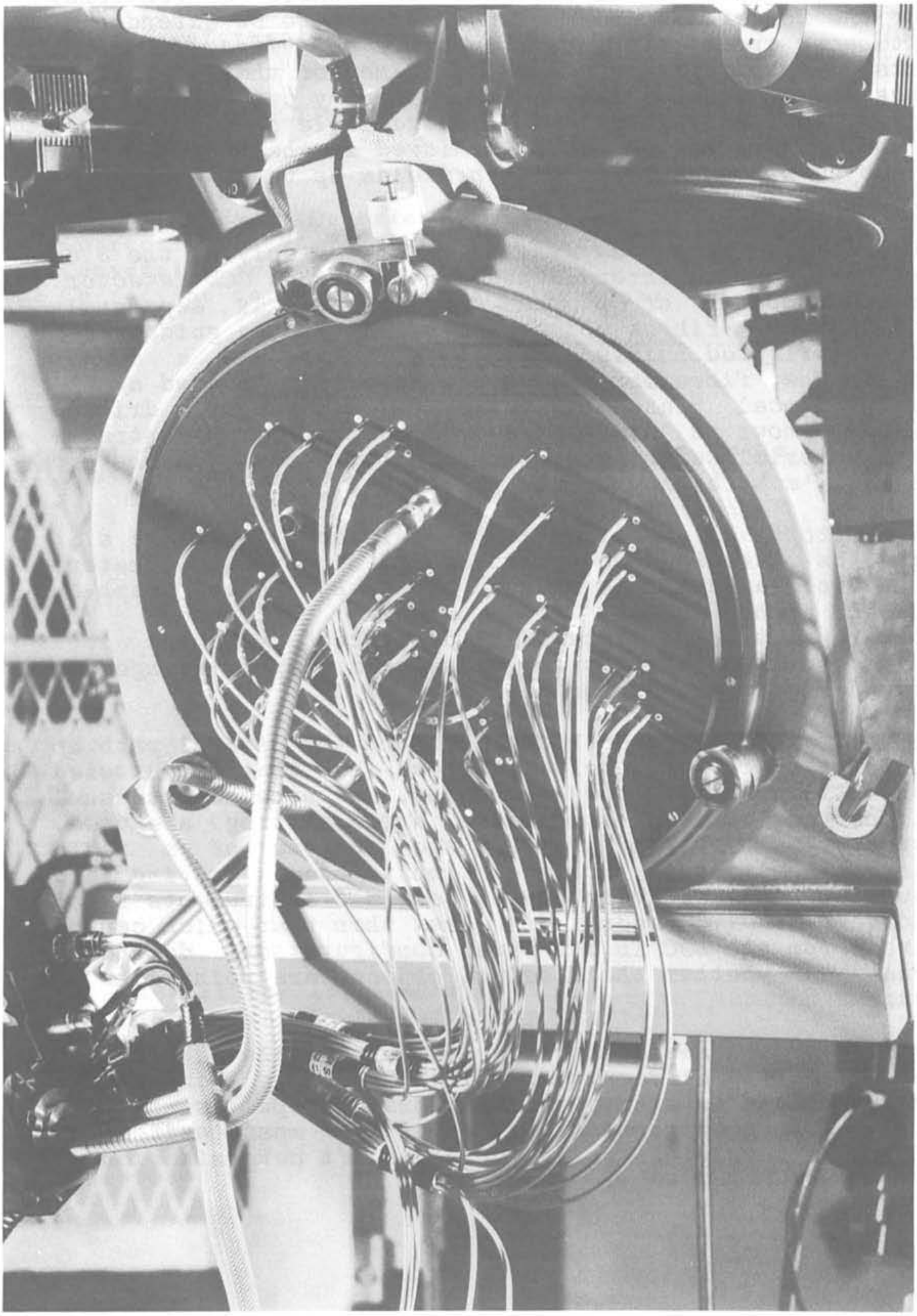
At present, Optopus is available for use only at the 3.6m telescope, and is intended to be used with a CCD detector. The fibre component of Optopus consists of 54 separately cabled optical fibres which enable light to be guided from freely distributed points in the focal plane to a common "slit". The fibre input ends are precisely located at the telescope focal plane by means of accurately drilled templates, known as "starplates". The spectrograph entrance slit is materialised by the fibre output ends, which are arranged in a straight row and polished flat.

When Optopus is installed at the telescope the fibre slit housing is attached to a devoted F/3 dioptric collimator, and the whole assembly is mounted on the B&C spectrograph in place of the usual F/8 off-axis collimator. The spectrograph, which is laterally displaced by about 1.5m from its usual position at the Cassegrain adaptor flange, is fixed underneath the mirror cell.

In the Optopus mode of B&C operation, the optical path up to the grating is completely different from that encountered in conventional use of the instrument, and none of its usual functions (except for the grating angle setting) are used. The spectrograph serves in effect the purpose of a rigid mechanical structure between input beam, grating and detector. The sensitivity of the combined instruments is of the order of 1.5 magnitudes less than that which can be expected from the B&C in its usual configuration, depending somewhat on whether the observed objects are point-like or galactic.

Because of the small entrance aperture of the fibres (2.5 arcsecs), and the difficulty involved in making accurate sky subtractions and intensity calibrations, Optopus is not well adapted for spectrophotometry. It is most suited to applications involving surveys or red-shift determinations.

FIGURE 1



II INSTRUMENTAL LAYOUT

II-a) Optical layout

The optical fibres have a core diameter of 133 µm, and are terminated at their free ends in miniature precision connectors for fixation into the focal plane starplates. Each fibre is preceded by a telecentric microlens mounted within its connector. The microlens is designed to convert the Cassegrain F/8 beam to an air equivalent of F/3 at the fibre input, and the fibre core thus provides an entrance aperture equivalent to a 2.6 arcsec spot on the sky. The conversion to F/3 is intended to reduce beam dispersion (focal ratio degradation) within the fibre, and to allow the use of smaller fibres and connectors.

Whereas in conventional spectroscopy the star image and spectrograph slit lie in the same plane, they are separated in Optopus by a length of fibre (Fig. 2). Neither the sky aperture at the entrance end, nor the output "slit width" can be adjusted as with a conventional spectrograph entrance slit. The fibre output beams feed into an F/3 collimator designed especially for Optopus. The collimator incorporates motorised focusing and shutter units, and a manually operated lateral slide for order-sorting filters (see II-d).

The optics of the collimator are optimised for the B&C plus F/1.44 Schmidt camera configuration, providing virtually unnoticeable image degradation over the entire CCD, for the wavelength range from 3600Å to 10000Å. Each fibre output is projected onto the detector with a monochromatic image size of 65 µm (2.2 pixels). By virtue of interstitial spacers used between active fibres, a blank spacing of about 4 pixels is achieved between adjacent spectra.

It is also possible to use Optopus with the PCD F/1.9 rather than the Schmidt camera, as described in (VI-a). The greater focal length of this camera results in a small increase in the number of detector pixels covered by a fibre image.

II-b) Starplates

In order to accurately locate the fibre ends in the telescope focal plane, a predrilled starplate is required for each observed field (Fig. 1). Details of the preparation procedure are given in part III of this manual. In Table 1 the physical limitations and constants imposed on the starplates are listed.

MULTIPLE OBJECT SPECTROSCOPY WITH OPTOPUS

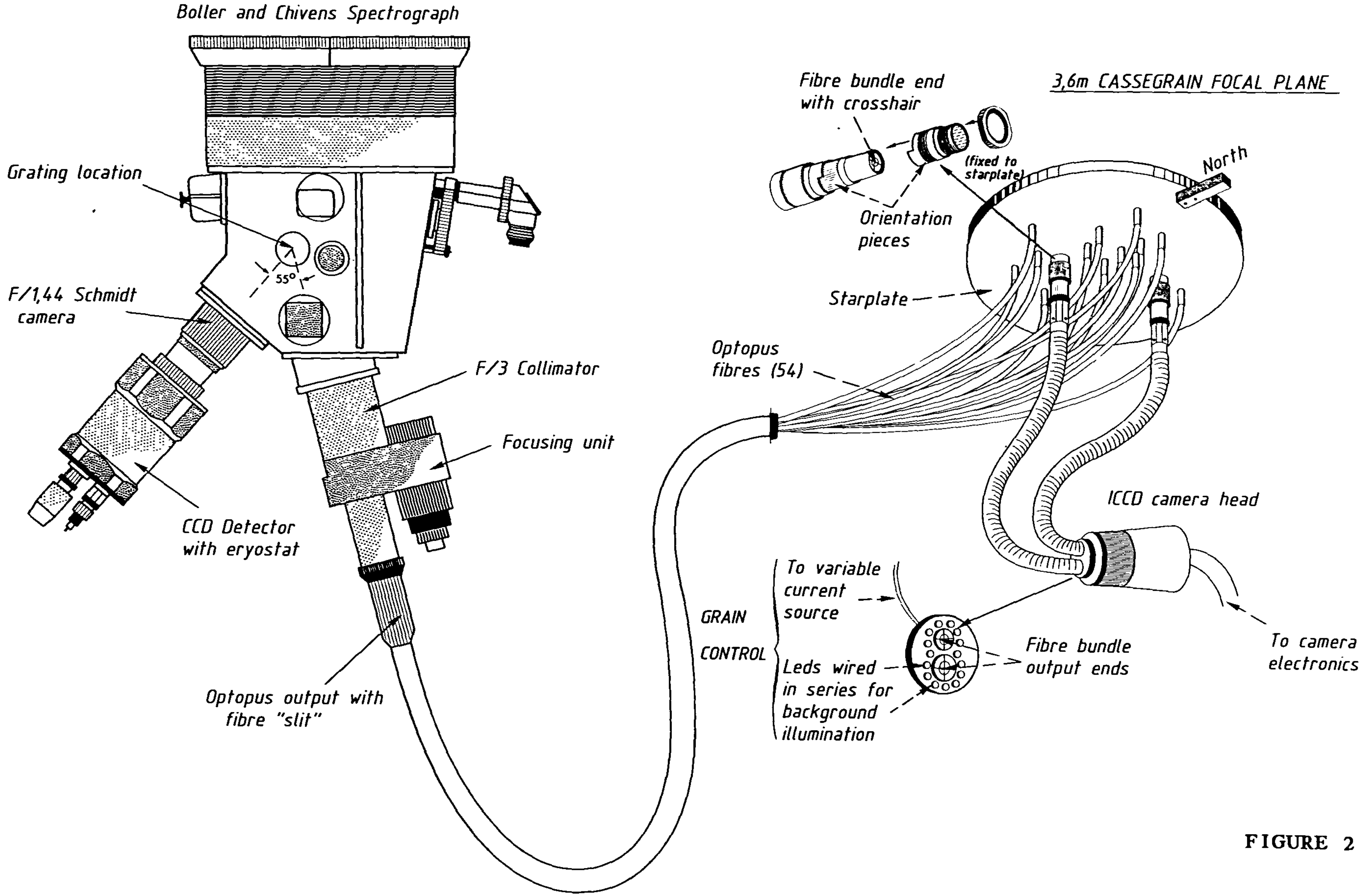


FIGURE 2

The fibre connectors are held firmly in the starplates by means of annular plastic inserts which are pressed into each "starhole" after drilling. The holes have a two-step profile with a shoulder, whose depth is calculated in such a way as to compensate for the curvature of the Cassegrain focal plane.

The field scale, given in Table 1 as 7.140 arcsec/mm, was determined experimentally from photographic plates recorded specifically for this purpose at the Cassegrain focus. There are small local variations in field scale, which do not appear to be entirely consistent from one plate to another (probably due to hour-angle variations in differential atmospheric dispersion), but which rarely amount to image displacements of more than 0.5 arcsec from the positions predicted by the above conversion factor.

II-c) Comparison Sources

The Optopus adaptor is fitted with three lamp housings for calibration exposures:

1) Quartz-halogen white lamp	*(Osram 6V, 10W, type 64225)*
2) He hollow cathode source	*(Philips Helium, type 93098)*
3) Ar hollow cathode source	*(Philips Argon, type 93100)*

The calibration beams are diverted upwards, by means of a small mirror, to the telescope secondary mirror. Although the secondary reflection can in principle be used for calibration exposures, these will be obtained with a very narrow beam and excessive exposure times. It is recommended to use the recently installed white screen which swings into place a few metres above the primary mirror, and provides a more luminous and authentic simulation of the telescope pupil. The screen position is selected from the control room.

Twilight exposures could also be useful for measuring the relative spectral efficiencies of the fibres, as described in (V-e).

II-d) Order-sorting Filters

As for normal use of the B&C spectrograph, coloured order-sorting filters are available with Optopus. The filter assemly is fixed at the input end of the F/3 collimator, between the Optopus fibre-row protection window and the collimator field lens. The filter setting is changed manually (by a member of the Optics group at La Silla !), by unscrewing the Optopus head from the collimator and sliding the filter holder to the desired position. Care must be taken to ensure that the head is always correctly replaced, and screwed back into complete contact with the collimator reference surface (see IV-d).

These operations should be done at the time of changing gratings or grating settings, and must ALWAYS be followed by a refocusing of the collimator, (Operations group).

The filter-holder supports two 5.0 mm x 27.0 mm filters of the following types;

1) BG 40, 1mm thick (blue, 1st-order rejection - see Fig.4)
2) GG 495, 2mm thick (red, 2nd-order rejection - see Fig.4)

For the given filters the theoretical changes in focus position, compared with the no-filter setting, are respectively +0.698 mm and +1.414 mm. These correspond to changes of approximately 450 and 950 units in the position readout of the collimator encoder.
Should a different type of filter be needed, it can be PROVISIONALLY inserted into the third (empty) space in the filter holder. The filter must have the dimensions 5.0 mm x 27.0 mm, and may not be thicker than 2.0 mm.

II-e) Guiding System

As the observed stars are not imaged onto the B&C entrance slit, the conventional slitviewing camera cannot be used for guiding.

The Cassegrain adaptor large-field camera can be used for initial acquisition, but must be removed to the field edge before starting exposures since the unparked mirror would partly obstruct the starplate field. Similarly, the offset guideprobe must be kept in its parked position.

As depicted in Fig. 2, Optopus has its own guiding system requiring two guidestars. The guidestar images, for which holes with special orienting inserts are prepared in each starplate, are picked up by two flexible coherent fibre bundles and fed to a TV camera. This camera is of the (non-integrating) intensified CCD type, and incorporates a small separate head with a fibreoptic input window, permitting direct image coupling from the fibre bundles without the use of transfer lenses (see Fig. 3). Engraved reticles are precisely cemented at the mechanical centre of the input ends of each guide bundle, enabling the observer to simultaneously appreciate the correct alignment of both guidestars.

The two-guidestar requirement arises from the need to bring the starplate into accurate rotational alignment (around the optical axis) with respect to the observed field. In Table 1 it can be seen that 3 guidestars are prefered to 2. This condition provides a measure of additional safety in the case of an error made in determining the coordinates of one of the guidestars. The error may not be due to incorrect measurements on the photographic plates, but to a proper motion of the star itself.

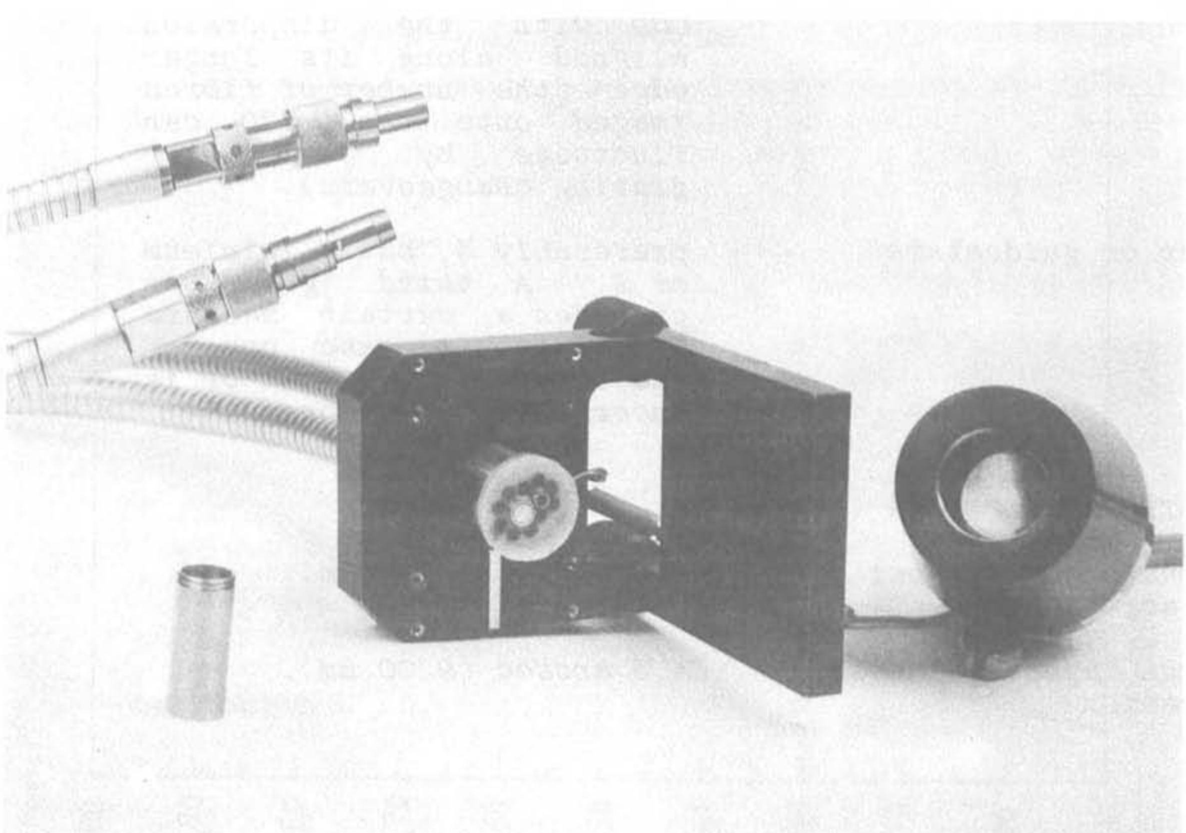
It may also happen that due to the use of low resolution plates an apparently single guidestar turns out to be double, making accurate guiding impossible.

Rotational movement of the starplates, assured by a motorised spindle within the adaptor housing, can be controlled from the 3.6m control room. The adjustment range is ±3 degrees, with a maximum resolution equivalent to 0.03 arcsec on the sky (at the field edge).

ONCE THE B&C SPECTROGRAPH HAS BEEN FIXED TO ITS SPECIAL SUPPORT STRUCTURE WITHIN THE CASSEGRAIN CAGE (see IV-c), THE CASSEGRAIN ADAPTOR UNIT MUST NOT BE TURNED, as a collision between adaptor components and the fixed B&C structure is possible.

Since the gain control of the TV camera is automatic and cannot be readily modified for manual adjustment, this function is simulated by means of a "dummy" variable luminous background within the camera head. As shown in Figs. 2 & 3, a chain of small LEDs is fed by a pulsed current source, and the global LED luminance is adjusted by means of a potentiometer situated in the control room. The on/off control switch for the TV camera is also situated in the control room.

FIGURE 3



III PREPARATION OF OBSERVATIONS

III-a) Physical Constants and Constraints of Starplates

The following data outlines the geometrical constants and physical limitations which should be kept in mind when selecting objects to be observed with a given starplate. Some of these constants are used within the OCTOP software (see III-f) to eliminate objects which are too far from the field centre or too close to a guide star, or to warn the user of any pair of objects which are too close together.

TABLE 1

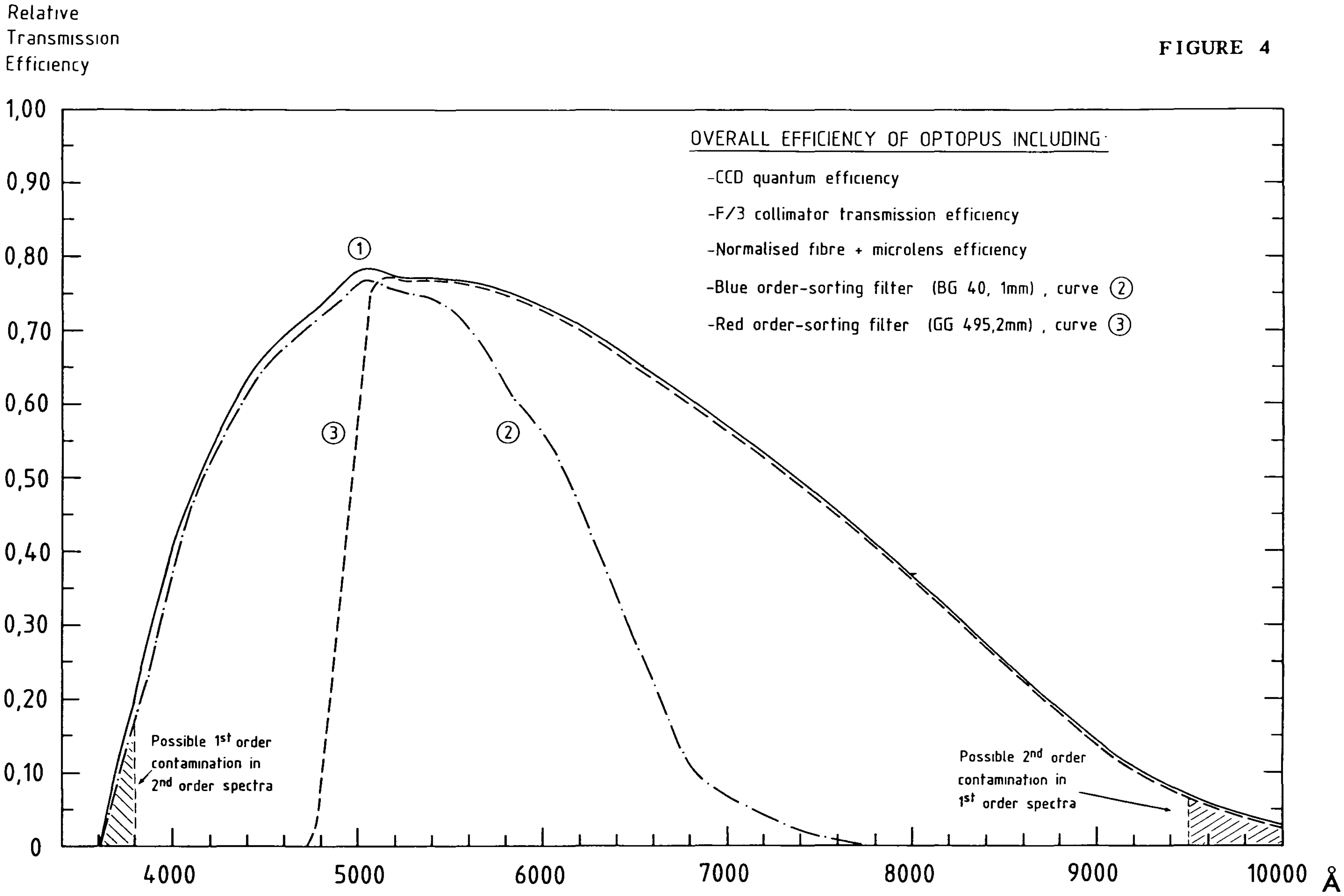
STARPLATE AND FIBRE CONSTANTS :

* *Field scale*	-	*7.140 arcsec/mm (0.1402 mm/arcsec).*
* *Maximum starplate field*	-	*33 arcmin (274 mm) diameter circular field.*
* *Fibre size on the sky*	-	*2.6 arcsec diameter (5.3 sq. arcsec aperture).*
* *Maximum No. of objects*	-	*48, using the RCA SID 510 EX CCD with the dispersion aligned along its longer edge (the number of fibres imaged onto the CCD can fluctuate by ±1 after grating changeovers).*
* *Number of guidestars*	-	*preferably 3, but a minimum of 2. A third guidestar provides a certain measure of safety, in case one of the others is too weak or is incorrectly positioned).*

PROXIMITY RESTRICTIONS :

* *Minimum object-object separation*	-	*24.6 arcsec (3.45 mm).*
* *Minimum object-guidestar separation*	-	*64.3 arcsec (9.00 mm).*

FIGURE 4



Relative
Transmission
Efficiency
1,00
0,90
0,80
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0
4000
5000
6000
7000
8000
9000
10000
Å
OVERALL EFFICIENCY OF OPTOPUS INCLUDING:
-CCD quantum efficiency
-F/3 collimator transmission efficiency
-Normalised fibre + microlens efficiency
-Blue order-sorting filter (BG 40, 1mm) , curve ②
-Red order-sorting filter (GG 495,2mm) , curve ③
①
②
③
Possible 1st order
contamination in
2nd order spectra
Possible 2nd order
contamination in
1st order spectra

OTHER CONSTRAINTS :

* *Recommended relative locations of guidestars*	- *15 arcmin or more linear separation.* - *90 deg. or more angular separation, with respect to the field centre, (an opposition close to 180 degrees is ideal)*
* *Faintest guidestar magnitude*	- *16 (v).*
* *Faintest object magnitude*	- *19 (v) at 114 Å/mm (see III-b)*

III-b) System Efficiency and Limiting Magnitudes

When compared with the B&C used directly at the Cassegrain focus, the Optopus system differs essentially in the transparency of the fibres (including input microlens) plus F/3 collimator, compared with that of the F/8 mirror alone. In this sense, the comparative efficiency of the instrument starts to drop at wavelengths below 4400Å where the fibre and collimator absorptions become increasingly strong. In Fig.4 the combined efficiencies of the F/3 collimator, RCA CCD (# 3), and fibre (normalised to unity at 5000Å) are shown as a function of wavelength. It should be noted that this CCD has a particularly high quantum efficiency at 5000Å (94%). Fig.4 includes two additional curves which show the effect of including either of the two order-sorting filters in the efficiency computation.

Since the fibres are not individually guided onto their respective objects during an exposure (the whole starplate being guided via two guidestars), it is important to realise that the total efficiency in collecting photons from a particular source will also depend strongly on the accuracy with which its fibre is correctly centered on its respective object. Approximate values for the various factors contributing to the fibre/object decentering are given in the Table below;

Table 2

Guidestar proper motion (rms)	*0.024 arcsec/year*
ESO Optronics/operator meas. uncertainty	*0.40 arcsec*
Cass. focus scale error (ave. over 30' field)	*0.25 arcsec*
Fibre connector/hole drilling pos. error	*0.15 arcsec*
Microlens induced image offset	*0.50 arcsec*
Guiding errors (in autoguiding mode)	*0.10 arcsec*
Atmospheric refraction	*- see (III-e)*

From Table 2 it can be seen that it is important for the object and guidestar coordinate data to be measured as accurately as possible. If, as in most cases, the astrometric source files used for starplate preparation are derived from photographic plates, the user should avoid selecting very bright guidestars since saturated photographic images will lead to inaccurate determination of the guidestar centroid coordinates. It is preferable to use recent photographic plates for the reduction of Starplate coordinates (whenever possible), in order to minimise the time-dependant effect of guidestar proper motion (typically 0.8 arcsec rms for stars measured on a Palomar 1950 Survey plate). This is generally not a problem for object coordinates, unless they also happen to be stars. In some cases it may be possible to find an SAO Catalogue star within an Optopus field, and to replace its measured plate coordinates (which are given for the 1950 epoch by the ESO POS reduction program) with the catalogue value.

As a guide to the performance which can be expected from Optopus, typical results obtained from test exposures in March 1985 are summarised below. Note that the exposure times are limited to something like 1 1/2 hours by the cosmic ray event frequency recorded by the presently used RCA detectors (0.08 events per sec per cm^2, for events with more than 60 e$^-$). It is often preferable to make two shorter sequential exposures, enabling a data reduction frame-comparison algorithm to be used to remove radiation events (see VII-b).

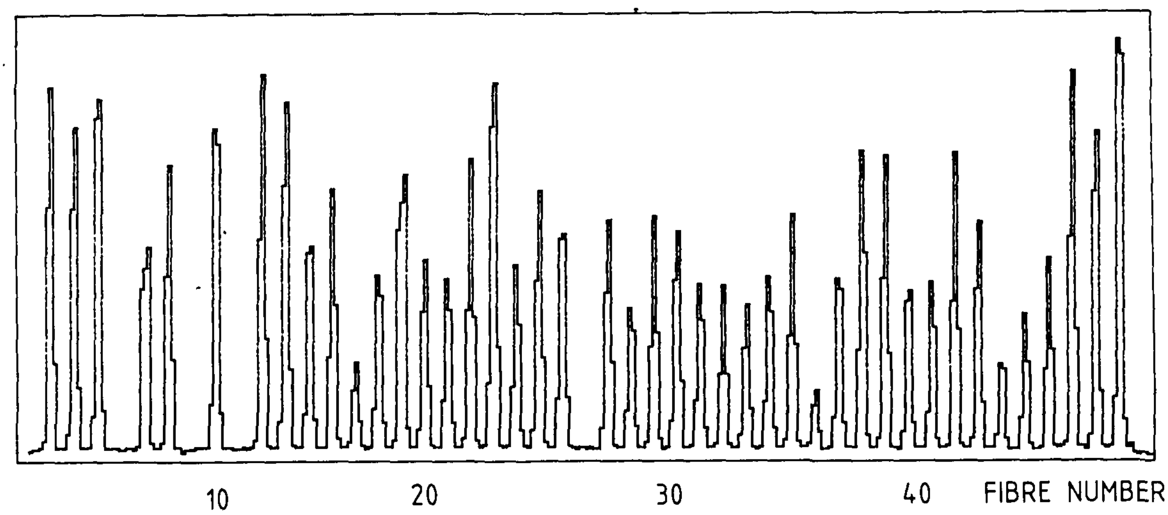
TABLE 3

Example # :	1	2
Detector :	RCA CCD (ESO #3)	RCA CCD (ESO #3)
Grating :	# 7 (114 Å/mm)	# 2 (224 Å/mm)
Resolution :	5.6 Å	11.2 Å
Wavelength range :	3800 - 5600 Å	4000 - 7500 Å
Exposure time :	80 minutes	90 minutes
Typical object mag.(V): (integrated over the 5.3 square arcsec fibre aperture)	18 (galaxy)	19 (star)
Typical SNR obtained :	~10	~10

It should be noted that the above magnitude limits can be improved by the use of the PCD dioptric spectrograph camera and on-detector binning (see VI-a).

It must not be overlooked that the overall system efficiency varies quite considerably from one fibre to another due to optical defects which arise mainly from imprecisions in the connector microlenses. The relative throughput of the fibres (with the Schmidt camera) can be appreciated from Fig. 5, which was obtained from a cut through a twilight sky exposure made in December 1985. The individual fibre throughputs are not represented by the maxima, but by the surface integral under each spike. It can be seen that 4 of the fibres (Nos. 6,9,11 & 26) are broken.

FIGURE 5



III-c) Sky Subtraction

The subject of sky subtraction should be considered carefully when planning observations with Optopus, since the system transmission efficiency varies from one fibre to the next.

If quite short exposure times are required on a particular field, it may be safe to assume that the night sky emission varies insignificantly during the exposure, and that a second exposure taken with the telescope offset by some small angle (say 20 arcsecs) will provide accurate sky-subtraction information.

With longer exposures in which sky subtraction plays a critical role, it is preferable to include several judiciously placed "sky" fibres in the starplate drilling coordinates. As quite strong variations are found in absolute transmission from one fibre to the next, accurate reduction of sky-dominated raw spectra will be difficult;

Careful calibration procedures (including dark subtraction, cosmic ray elimination, as well as wavelength and (twilight) flat-field calibrations) are needed in order to correctly infer, from a "sky fibre", the contribution to be subtracted from an object spectrum recorded at the same time with a different fibre.

III-d) Correction for precession

Experience has shown that a correction for coordinate precession before drilling of the starplates can prove particularly useful when it finally comes to acquisition of the two guidestars at the telescope. The reason for this is that precession affects not only the absolute centre coordinates, but also gives rise to a small rotation of the field. Although the change in field-centre coordinates is taken into account by the telescope computer, the degree of field rotation will (unless calculated by the astronomer) be unknown, and will require empirical compensation by means of the starplate rotator. In practise this can often lead to considerable time wastage, due to the additional unknown factor of the telescope pointing inaccuracy for a given sky position.

The precession software available on the ESO VAX computer (MIDAS) should be used for these corrections, as they are not available on the HP 1000. It is hoped to integrate this as an interactive facility within the OCTOP program, once this has been implemented on the VAX.

III-e) Correction for atmospheric refraction effects

If not corrected for, the distortion effects introduced by atmospheric refraction can lead to significant hole-positioning errors, especially in the case of an exposure made at a large zenith distance. There are two effects which should be distinguished;

- *Differential refraction at a given wavelength.*
- *Chromatic dispersion.*

Both effects are are implicitly expressed in the following relation, which models the atmospheric refraction with sufficient accuracy for the purpose of OPTOPUS starplate corrections;

Apparent Image Shift (arcsecs) = k(lambda).tan(Z)

where k (for La Silla) is approximately 44.2 arcsecs for a wavelength of 5500Å.

Assuming a starplate to be guided correctly onto the apparent centre of a field, the maximum DIFFERENTIAL effect, for an object situated at the field edge (ie 15 arcminutes distant) is simply;

Max. Diff. Offset (arcsecs) = 44.2 {tan(Z+0.25°) - tan(Z)}

For zenith distances of 40°, 50° and 60°, the maximum differential offsets given by the above formula are respectively 0.30, 0.43 and 0.71 arcsecs.

The CHROMATIC effect arises from the wavelength dependance of k, and will depend on the wavelength response curve of the TV guide-camera as well as on the spectral emission of the guidestars chosen for each starplate. As an example, in a field observed at a zenith distance of 40 degrees an atmospherically induced offset of 0.63 arcsecs occurs between a star imaged at 4500 Å and the 'colour centroid' (6400 Å) of the camera's responsitivity curve.

Clearly, without the use of special atmospheric refraction-correcting optics in the Cassegrain focal plane, it is not possible to correct for atmospheric dispersion at more than one wavelength. Nevertheless, it is possible to offset the guidestar coordinates in order to achieve a useful compromise, particularly for observations made at the blue end of the visible spectrum.

Corrections for the differential and chromatic coordinate offsets can be implemented using a program called 'ATREF' (see III-f). The philosophy of this program is described in the following;

For given field-centre coordinates, specified observation time slot and wavelength range of interest, ATREF determines; (a) an optimal differential correction vector (to be duly scaled according to the coordinates of each object), and (b) an optimal chromatic correction vector for the guidestars. In (a), the algorithm is based on the calculation of a zenith-angle weighted time integral of the differential offset function. In the case of (b), the central wavelength computed for use in the chromatic corrections is weighted according to the refraction wavelength dependance expected for the altitude and humidity of La Silla. This wavelength is always biased towards the bluest end of the spectrum, where the atmospheric dispersion effects are the strongest.

When running ATREF, the user has the opportunity to inspect the computed optimal hour angle and zenith angle values, and to redetermine the defined observation slot as often as he wishes. The sidereal time for which the corrections are finally computed can be imposed by the user. Clearly, it will be impossible to define the exact time at which an exposure will actually be made at the telescope. However, as a general rule the astronomer will try to observe his fields in the order giving the least possible overall hour angle (airmass). These decisions can be made in advance, thus enabling him to define a time slot of some 2 or 3 hours in which a given plate will probably be used.

As a general rule, the corrections are well worth making, particularly for exposures to be made at high zenith distances (⩾30 degrees), provided the starplate is used within +- 1.5 hours of the recommended optimal time slot. The consequences of using the corrected plate at a completely different hour angle from that for which it is intended can be readily checked by re-running ATREF and imposing the corresponding time slot.

III-f) Preparation of Starplate Drilling Data

The starplates are prepared in an automatic process in the ESO workshop in Garching, using recorded CNC machine instructions. For this purpose, astronomers using Optopus are required to travel to Garching at least two months in advance of their observing run at La Silla. ESO supports this trip as an integral part of the observing program, provided the astronomer belongs to an institute from one of the member states. Because of the time and cost involved in the preparation of each starplate (half a day's machining in the workshop and around 250Dm in materials), it is important for the astronomer to request only the number of plates he will actually be able to use:

Allowing for the time needed to changeover starplates and to make customary calibration exposures, it is expected that NOT MORE THAN 4 (in summer) or 5 (in winter) STARPLATES CAN BE USED IN ONE NIGHT. These figures are imposed by ESO as a practical limit, unless a justified request for a larger quantity of plates is approved by the head of the Instrumentation Group in Garching.

It is the astronomer's responsability to reduce his coordinate data, according to the steps set out below, in order to produce for each starplate a drilling instruction file which can be directly fed to the workshop's programmable milling machine;

* *Preparation of correctly formatted equitorial coordinate data for each field,*
* *Running of the interactive data conversion program OCTOP ,*
* *Running of the interactive atmospheric refraction correction program ATREF , (as described above)*
* *Running of PLOCT to obtain a graphic XY plot of the drilling coordinates,*

If the user derives his astrometric files from the ESO plate measuring facility (OPTRONICS), it will automatically have the appropriate format containing;

1) Identifier	*(from 25000 to 25999 for objects)* *(from 26000 to 27000 for guidestars)*
2) Right Ascension	*(hh mm ss)*
3) Declination	*(sign Deg Min Sec)*

Obviously, the coordinates must be corrected to the same equinox for objects and guidestars.

For those users who wish to provide their own astrometric files from other sources, the exact data formatting required is demonstrated by the example set out below ...

```
0001  C NGC 6626    Starplate Example

0002      25001 18 20 43.749   -24 54  6.49

      (ident.)(hh mm ss    ) (sign deg min sec)

                        etc.
```

Note that if the starplate programs are run on the HP 1000 computer;

- *the decimal points are represented by a dot (.) and not a comma (,).*
- *the position of the sign preceding the declination must not change EVEN if the degrees are less than 10. Example: - 8 39 18.85 and NOT -8 39 18.85!*

This last comment is important for those who use the ESO MIDAS software to prepare their files, since this system uses a floating format. We again stress the importance of using data corrected to the same equinox for both object and guidestar coordinates.

At the time of writing, the Optopus programs described here (OCTOP, ATREF, PLOCT, PLOCZ, and TEMPL) are run on the HP 1000 measuring machine computer in room 072 at Garching, although the whole system is hoped to be implemented on the VAX by the end of 1986 (*). For those using the starplate preparation system for the first time, an ESO staffmember will be available if an introduction is needed.

When working with the HP1000, the terminal requests; "Security Code:?" and "Cartridge No.:?" , which appear in the course of running these programs, should be answered respectively by "OC" and "4". The interactive programs OCTOP and ATREF are initialised simply by entering "OCTOP" or "ATREF" following the File Manager prompt (:).

When OCTOP is run, the input and output file names are requested, and the user is asked if he wants to provide his own field centre coordinates. By default the program determines its own field centre according to the median of the α and β extremes in the astrometric file. Occasionally, a 'nonsense' output file is produced after requesting an automatic centre determination, in which case it will be necessary to start again and manually enter one's own field-centre coordinates.

** At the time of writing ATREF can also be run on the VAX in Garching (using Username = ESO, Password = Lasilla).*

TABLE 4

(A,D)-Positions from file: G1808A

Ident: NGC 1808: OPTOPUS-DEC. 1985 PREPARATION, GARCHING

	X(µm)	Y(µm)		Obj. #	Z(µm)	Hole #	
0001	-23375	77215	0	26003	-1585	1001	
0002	-71792	-49666	0	26010	-1759	1002	Guidestars
0003	59397	-94888	0	26013	-2525	1003	
0004	-130	-3025	0	25904	-1491	1	
0005	-5182	-9271	0	25905	-1508	2	
0006	10975	-41863	0	25990	-1782	3	
0007	-39086	55101	0	25992	-2202	4	Objects
0008	-62083	-39045	0	25994	-2329	5	
0010	60278	-81256	0	25996	-3087	6	
0011	-18086	-16047	0	25998	-1581	7	
0012	3899	4472	0	25004	-1495	8	
0013	11527	10952	0	25013	-1529	9	
0014	22846	20700	0	25016	-1638	10	
0015	32668	22533	0	25017	-1736	11	
0016	33375	-3461	0	25019	-1666	12	
0017	30932	-21826	0	25021	-1714	13	
0018	19175	-9803	0	25022	-1562	14	
0019	-9297	-24695	0	25024	-1599	15	
0020	-8791	-10917	0	25028	-1521	16	
0021	-17709	-11637	0	25030	-1560	17	
0022	-22451	-15675	0	25104	-1607	18	
0023	-24360	-7084	0	25106	-1590	19	
0024	-28450	4569	0	25111	-1620	20	
0025	-28111	15262	0	25115	-1650	21	
0026	-40483	-4718	0	25117	-1749	22	
0027	8687	22588	0	25121	-1581	23	
0028	36500	7692	0	25126	-1707	24	
0029	36731	-10996	0	25129	-1719	25	
0030	11268	-13841	0	25134	-1540	26	
0031	21209	-66230	0	25137	-2244	27	
0032	28776	-100229	0	25141	-3186	28	
0033	72029	-102063	0	25142	-3924	29	
0034	31011	-114256	0	25145	-3677	30	
0035	-17126	-114051	0	25150	-3565	31	
0036	-49216	-100327	0	25151	-3438	32	
0037	-76717	-72253	0	25156	-3223	33	
0038	-48013	-58076	0	25163	-2376	34	
0039	-110656	5494	0	25173	-3405	35	
0040	-62947	10806	0	25176	-2126	36	
0041	-87170	15277	0	25179	-2712	37	
0042	3514	49258	0	25190	-1870	38	
0043	14723	55381	0	25191	-2002	39	
0044	33532	44154	0	25192	-1970	40	
0045	45108	63716	0	25198	-2441	41	
0046	64788	57715	0	25216	-2664	42	
0047	81127	63895	0	25218	-3154	43	
0048	110859	72115	0	25221	-4218	44	
0049	57095	713	0	25228	-1999	45	
0050	108278	-1119	0	25237	-3319	46	

The field centre is associated with the coordinates (X=0,Y=0), and MUST BE CAREFULLY NOTED as it will later be needed as an input to the program ATREF and for correct pointing of the telescope.

The program OCTOP first converts the astrometric file into a correctly scaled and centered XY file, and outputs the following information:

- *all computed XY coordinates, with their identifiers,*
- *objects eliminated because they lie outside the field limitations,*
- *objects eliminated because they lie too close to a guidestar,*
- *objects (pairwise) which are in competition because of their proximity.*

In the case of the proximity warning, the program requests one object to be selected for elimination. At this stage it is a good idea for the user to come prepared with a listing of his astrometric file, a finding chart, and any other information necessary to help him make a sensible decision.

There is no harm in starting with an overloaded field and then eliminating objects until a suitable number is reached. Care should however be taken to avoid eliminating more objects than necessary in cases where several are grouped closely together, and one (or more) object is included in several competing pairs - as OCTOP does not update its object list until all elimination decisions have been made.

When all unallowed objects have been removed, OCTOP outputs onto disc a final XYZ file (whose filename is defined by the user at the begining of the run). This file can be printed out with the HP1000 using the commands ... :LL,6 followed by :LI,'filename'. On the VAX system, the instruction $ laser 'filename.' is sufficient. This listing will later be essential for identifying hole (and fibre) numbers with their correct object.*

A sample XYZ output file is given in Table 4, (dimensions are in microns). The Z coordinate, which is needed to correct for the Cassegrain field curvature, is given by the formula;

$Z = K + 1.56\ 10^{-7}(X^2 + Y^2)$ *where K is a constant related to the connectors.*

For the use of ATREF, sufficient information is provided on the monitor to enable the program to be run correctly by an unitiated user. Table 5 shows a sample listing resulting from a run of ATREF.

TABLE 5 : SAMPLE OUTPUT LISTING FROM ATREF

```
FIELD TO BE OBSERVED : TEST EXAMPLE
NAME   OF   OBSERVER : JOE BLOGS
NAME OF  INPUT  FILE : XYNGC1:OC:4
NAME OF  OUTPUT FILE : XRNGC1:OC:4

FIELD    COORDINATES :  2:35:47  -5:23:49
OBS DATE (Day Month) : 27  7


Darkness will begin at ST = 14.31
Darkness will  end  at ST =  1.90


Expected time of observation : from 22.00 to  1.00


OPTIMAL TIME  FOR  CORRECTION  DETERMINATIONS :    22.85

OPTIMIZED OBSERVATIONAL HOUR ANGLE IN DEGREES :   -56.67
CORRESPONDING   DISTANCE  FROM   THE   ZENITH :    58.45
MAXIMUM  NECESSARY  CORRECTION  (IN  ARCSECS) :     0.71
DIRECTION OF CORRECTION VECTORS ON  STARPLATE :   -58.81
(ie.  Perpindicular to the projection of  the
      horizon on the starplate at  the  above
      determined hour angle ).

WARNING !  The  corresponding  range  of  hour  angles,  ie. from
-68.95 to -23.95 degrees  COMES CLOSE TO THE TELESCOPE  LIMITS !!!


CHOSEN SID. T. FOR OPTIMISATION :   23.00
CORRESPONDING HOUR ANGLE (DEG.) :  -53.95
FINAL OPTIMAL  ZENITH  DISTANCE :   56.14
FINAL MAXIMUM ERROR (IN ARCSEC) :    0.62
FINAL CORRECTION VECTOR  (DEG.) :  -58.15

CHOSEN  LENGTH  OF  OBSERVATION :    60 Minutes
APPROX. OPTIMAL OBS. SLOT  (ST) :   22h 39m  to 23h 39m
CORRESPONDING OBSER. SLOT  (UT) :    6h 57m  to  7h 57m
CORRESP. RANGE OF CORR. VECTORS :  From -59  to -54 deg.


WAVELENGTH RANGE FOR OPTIMISATION :  3800 to 5400 Angstroms
OPTIMAL WAVELENGTH FOR CORRECTION :  4329 Angstroms
NEEDED CHROMATIC CORRECTION  IN X : -131. Microns
                      and    IN Y :   81. Microns
```

The user can obtain a map of his final object, sky (if any) and guidestar coordinates by running the "PLOCT" program. The program asks the user if he needs an E W -flipped version of the map. Normally, only the unflipped version (corresponding to the appearance of the starplate from the machined side) is needed. This map has North at the top and East to the left, and will be needed at a later stage to assist with correct numbering of the starplate holes (see V-a).

If direct comparisons are needed with photographic plates which have East to the right, a FLIPPED map should be requested. The plots are produced, at a slightly reduced scale (× 0.9), with sequentially assigned hole numbers written alongside each object. If the plots are desired at exactly the same scale as that at which they are drilled, the program PLOCZ can be used instead of PLOCT. The PLOCZ maps do not provide hole numbering.

In order to be able to produce drilled starplates from the final XYZ files, the program TEMPL must be run. This program transforms the position coordinates into a long sequence of machine instructions, correctly formatted for the programmable milling machine in Garching. The structure of this sequence is embodied in an external file called DATEMP, which is designed to enable the machining to proceed with a minimum of manual intervention.

Data transfer software has now been developed to enable the machining programs to be fed directly from the ESO VAX computer to the milling machine, via a standard RS232 data cable. The transfer is initialised from a VAX terminal situated in the workshop.

So long as the Optopus programs are run on the HP1000 computer, the output drilling files will first have to be transfered to the VAX (as explained below);

The drilling instruction files are copied sequentially from the HP1000 onto magnetic tape using the instruction :ST,filename:OC:4, (where the '*' refers to the mag. tape driver LU number). The last store instruction should be followed by :CN,*,EOF in order to mark the end of file. The tape can then be reread onto the VAX using the instructions:*

$ ALLOW MTA0:	*(or MTA1: - depending on which tapedrive is free)*
$ MOUNT/FOR MTA0:	
$ COPY MTA0: filename.cnc	*(repeat this for each filename)*
$ DISMOUNT MTA0:	*(when finished)*

These operations will be taken care of by Garching staff, for whom a list of all XYZ and TEMPL output files should be prepared. A similar list should be made for the person responsable for the Garching workshop (S. Balon), who will handle the VAX-milling machine data transfer.

IV INSTRUMENT INSTALLATION

IV-a) Installation of the Optopus Adaptor

The Optopus adaptor flange is relatively light and can easily be installed by three men without the need for a hydraulic lift. If the B&C spectrograph happens to be already on the telescope, it should be removed and placed on a support which is high enough to facilitate later removal of the F/8 collimator.

The Cassegrain rotator position must be adjusted to 2700 (on the control room indicator). The Optopus adaptor should then be mounted so that the orientation pawl of a starplate will point approximately to the South of the dome (ie in the direction of the Cassegrain cage doors), in order to avoid later having to rotate the telescope adaptor through a large angle to achieve the same result. NOTE that this arrangement results in the electronics junction box facing 30 degrees West of South, ie. 30 degrees to the left when viewed from the cage entrance, (red pointers are marked on the Cassegrain and Optopus adaptor flanges to facilitate alignment). The Optopus adaptor must be installed BEFORE the B&C is mounted in the Cassegrain cage (see IV-c below).

IV-b) Installation of the F/3 Collimator

This job is to be carried out ONLY with the help of members of the Optics group at La Silla.

Firstly, the F/8 collimator must be dismounted from the B&C spectrograph and carefully stored in a safe place. A protective cover should be used to prevent dust from accumulating on the mirror. There are alignment marks on the spectrograph housing which can be of help when replacing the collimator.

When handling the F/3 collimator, extreme care must be taken to ensure that it is NOT SUBJECTED TO THERMAL SHOCKS. Some of the elements contain a high expansion glass which can break if it is suddenly heated or cooled. Normally, the collimator should have been left attached to its adaption flange since the previous Optopus run, in which case the complete assembly can be mounted onto the collimator in one operation. The adaption flange is fixed to the spectrograph, using the F/8 fixation screws, with the orientation depicted in Fig.2. The screw holes in the flange are intentionally oversized in order to permit some rotational freedom for alignment of the fibre row, as described in (IV-e). If the two units have been separated, care must be taken to observe the correct orientation when mounting the F/3 collimator onto the adaption flange.

This is achieved when the orientation pin at the threaded end of the collimator (and also the shutter connector socket) are pointing vertically upwards. Red Dymo labels with alignment pointers have been stuck onto the B&C, the adaption flange and the collimator to facilitate this procedure. Rotation of the collimator by 180 degrees from this position will have no effect other than reversing the order in which the spectra appear on the CCD.
The Optopus output head must NOT be attached to the colli tor until the B&C (with F/3 collimator) has been transported and installed in the cage. This precaution is necessary to avoid the danger of hitting the head against the floor or some other structure during installation, as it hangs down quite far below the spectrograph.

IV-c) Installation of the Boller & Chivens

. ıen used with Optopus the B&C must be fixed in the cage, within reach of the 2.5m long optical fibres. This is achieved with the help of a special support structure which allows the spectrograph to be firmly attached underneath the mirror cell, between the Optopus adaptor and the cage doors. The necessary fixation holes were made in the mirror cell in March 1985. It is very important to note that once the B&C has been fixed in place, THE CASSEGRAIN ROTATOR MUST NO LONGER BE TURNED, since a collision between adaptor components and the spectrograph can occur (a note to this effect should be stuck onto the rotator activation button in the control room). Fine rotational adjustments of the starplate are made using the Optopus rotation unit.

IV-d) Installation of the Fibre Optopus

The fibre output head is connected to the F/3 collimator with a tight sliding fit and is firmly held in place by means of a screw ring. Before fitting the two together, the head must be turned to bring its reference notch into alignment with the corresponding pin on the collimator. The loose end of the fibre bundle can then be attached to the fixation bar on the adaptor.

IV-e) Alignment of the Fibre Slit and Detector

The procedure outlined here is not imperative, but will later on greatly simplify the data reduction procedure by eliminating the need for a software rotation of the spectra (which generally introduces some noise into the data).

Firstly, as for standard use of the CCD, the detector/ Schmidt Camera assembly should be rotated until the spectra produced with the white calibration lamp are aligned as nearly parallel to the pixel lines of the CCD as possible.

This job is a little difficult owing to the weight of the detector/camera assembly and to the lack of a fine adjustment mechanism. An offset of one pixel between the extreme ends of the spectrum is acceptable. Ideally, this procedure should be repeated every time the grating is changed (provided, as is usual, that the changeover is made during the day), since each grating can introduce a slightly different rotation to the spectra.

Once the detector has been correctly aligned, the fibre/collimator/adaption-flange assembly must also be aligned, so that the axis of the fibre slit is orthogonal to the direction of spectral dispersion. An adjustment mechanism, provided near the bottom of the B&C housing, works by means of two screws which push against a reference bar projecting up from the side of the collimator adaption flange. The flange fixation screws must of course be loosened before each adjustment and tightened afterwards. One full turn of an adjustment screw corresponds to around 1 pixel of rotation between opposite ends of the fibre row, when it is imaged onto the detector. Pushing the reference bar to the left provokes an anticlockwise rotation of the image, and vice versa. The alignment of the monochromatic fibre row image can be checked after each adjustment by running a He or Ar calibration exposure. Any residual scatter in the alignment of the fibre row can be removed during data reduction by use of a special IHAP command (see VII-e). The fibre row alignment is generally unaffected by changes in grating.

IV-f) Grating settings

All the Bausch & Lomb gratings normally used with the B&C and CCD detector can also be used with Optopus. However with Optopus, the collimator/camera angle is increased by about 6° to a value of 55°, which has the effect of REDUCING by approximately 3° the normally required setting angles on the spectrograph. The recalculated values of grating position angle can be read off from the upper scale of the grating efficiency curves given in Figs. 6 at the end of the manual. In addition, Table 6 provides for each grating a setting constant K which allows the user to calculate a close approximation to the value of θ (Opt) required for a given central wavelength with the relation;

$$\theta\,(Opt)\ (degrees) = K\ \lambda_c\,(\text{Å}) \ - \ 3^\circ$$

The exact formula, which should be preferred for large setting angles of θ (Opt) is given by the expression;

$$\theta\,(Opt)\ (degrees) = \arcsin\,(5.637\ .\ 10^{-8}\ k\ n\lambda_c) \ - 3^\circ$$

In practice, it is in any case usual to make a final experimental determination of the needed grating angle setting, using one or two calibration lamp exposures.

The active length of the (RCA) CCD detector is 15.6 mm, and this will determine the spectral range observable with a given grating and order. The user is strongly advised to consult both the grating curves and the combined Optopus efficiency curve of Fig. 4 before final selection of grating and order.

IV-g) Electrical Connections

The various cable connections needed for Optopus will normally be made by one of the Electronics group members (see R. Parra).
All connections to the instrument, except for those related to the TV camera, are made via the Electrical Junction Box which is fixed to the Optopus adaptor. The Optopus functions of starplate rotation, collimator focussing and shutter, and calibration lamps are supplied from output Burndy or Lemo connectors situated on the righthand side of the Junction box. The necessary external input/output connections to the instrument, namely 230 V, CAMAC, NIM, HT supply for the He and Ar lamps, and controlled current supply for the white flat-field lamp are all made at the lefthand side of the Junction box.
The TV camera, which should be clamped to its fixation bar on the adaptor, requires a separate 6V power supply and a variable current source for manual gain control (see also II-e). These sources are installed in the electronic racks of the cage. The TV video signal can be sent to the control room by using the guideprobe camera connector at the BNC patchboard. The guideprobe camera, which is not used with Optopus, should be reconnected at the time of the next instrument changeover.
The Junction box, when switched to "local", is designed to enable all Optopus functions, except for the TV gain control, to be operated from the cage. The digital numeric display, which should be switched off during exposures, can be used to check the encoder positions of the plate rotator and collimator focusing unit.

IV-h) Collimator Focus Setting

The optimal focus setting is determined by a member of the Operations group, using the B&C Hartmann screens and a standard algorithm. The adjustment of the focus setting is achieved by remote control from the control room.
The axial chromatism of the collimator is such that a maximum blur of half a pixel can be incurred if it is focused in the uv and then used in the infrared.

Practically speaking, once the collimator has been focused a readjustment should not be necessary unless the user wishes to work at wavelengths above 8000Å. This should nevertheless be checked whenever the grating is changed.

V OPERATING THE INSTRUMENT

V a) Reception and numbering of Starplates at La Silla

Once all the starplates have been machined in Garching, they are packed with protective foam into photographic plate boxes and air-freighted to La Silla. The boxes are addressed to the corresponding observers and also contain, for each starplate, a fibre/hole correspondance worksheet (see also V-b) and a set of self-adhesive labels (see below).

The observer should endeavour to arrive a day early at the observatory, in order to have time to pick up his box(es) from the "Bodega" and to LABEL every hole on each starplate. The holes should be labelled, using the provided self-adhesive labels, in the same way as they are numbered on the PLOCT maps (ie according to the consecutive numbers assigned by the OCTOP program output). It is recommmended that great care be taken to avoid any errors, later leading to object misidentification.

V-b) Insertion of Fibres, and Starplate Changeovers

Starplate changeovers and fibre connections may be carried out ONLY by trained night assistants, one of whom will always be assigned to the 3.6m telescope for the duration of Optopus observation runs. This precaution is particularly important for the safeguard of the fibres, which could be damaged or broken if incorrectly handled. It is furthermore rather difficult for an inexperienced person to judge when the fibres have been pushed down to the correct depth in their guideholes.

Experience has shown that during plate changeovers on the telescope it is time-consuming to match fibre and hole numbers when the connectors are being plugged in. For this reason, the fibres are normally inserted (irrespective of their number) in the most convenient fashion from left to right (or vice versa) across the starplate, whilst the fibre/hole number correspondences are simultaneously noted by the astronomer. Correspondence worksheets are provided for this purpose with the starplates when they are shipped to La Silla, as mentioned in (V-a) above.

The Optopus adaptor has a hinged structure which is opened for eye-level mounting and removal of starplates and fibres;

the adaptor hinge has an autoclamping mechanism which tightens as it is opened, thus enabling the starplate support structure to remain firmly fixed in a vertical position.

A starplate is mounted on the adaptor by firstly opening the hinged roller bearing and rotation unit clamps, and then sliding the plate downwards until it rests on the other two rollers with its orientation pawl fitting into the plate rotation unit (see Fig.1). The clamps are then firmly closed, thus holding the plate down onto a sliding reference surface on which it can turn when the plate rotator is activated. The reverse procedure is used to remove a starplate.

In practise, it is more convenient to connect the guide bundles into the starplate first, before inserting the fibre connectors. As can be seen in Figs. 1 and 2, the bundles are held in place in the starplate by means of special inserts, to which they are fixed by means of a threaded collet. The inserts also serve the purpose of correctly orienting the bundle ends with respect to the sky.

The fibre connectors, starplate holes and plastic plate-inserts are made to high tolerances ensuring that the connectors can be reliably held in place by friction. The fit is therefore a little tight, and care must be taken to be sure that each connector is pushed in as far as it should go. An incorrectly inserted fibre will pick up a defocused image, resulting in a loss of photons. Connector holes should not be used more than once (for example to swap some fibres with different holes), because the plastic inserts are non-elastically deformed and will give a poorer orientation the second time.

A swan-neck reading lamp is provided on the instrument, to facilitate plate-changeovers and to avoid misidentification of hole numbers during fibre insertion. The lamp can only be switched on if the Instrument "Junction Box" is first switched from "remote" to "local". Switch back to "remote" before leaving the cage!

V-c) Guiding: Initial Alignment of the Starplate

Once the telescope has been pointed to the field centre of a particular starplate, the Cassegrain adaptor large-field camera can be used to trim the telescope pointing as well as possible. The camera should then be turned off and returned to its parking position at the field edge. At least one guidestar should now be on or near to the larger bundle, as it has a field of view of 35 arcsecs. Once one guidestar has been found, the other one must be searched for either by moving the telescope or by using the fast rotation movements of the plate rotator. When both guidestars have been detected, it is then a matter of combining iterative telescope displacements and plate rotations in order to bring both objects into correct alignment with their respective crosshairs.

If the guidestars have been chosen so as to have an adequate angular separation with respect to the field centre (see III-a), the observed images will be seen to move in quite different directions when the plate is rotated. This condition is rather important as it prevents a confusion from arising as to whether a telescope movement or a plate rotation is needed to achieve correct centering of both stars, and makes the whole alignment process rather straightforward.
Once the correct plate rotation has been established for the first starplate of an observation run, only very small adjustments (if any) are needed for the following plates.

An accurate approximation to the correct rotational position can be found at the beginning of an Optopus run, by using a special 'test' starplate and any convenient bright star (preferably during twilight to avoid wasting valueable darkness hours).
The test starplate is normally kept together with Optopus in its storage box, but should be requested beforehand from the optical or operations group. In addition to a compact annular distribution of object holes at the plate centre (used as described in (V-e) for standard-star exposures), the test starplate has 5 guidestar holes which are drilled respectively at the starplate centre and at exactly 300 arcsecs N, S, E and W from the centre.

The starplate should be mounted onto the adaptor, with the larger guide bundle connected at the field centre, and the smaller bundle at the North position. The telescope is then pointed to the selected star, and centered exactly on the large bundle.
The next step is to displace the telescope 300 arcsecs Southwards in order to bring the small bundle into nominally correct alignment with the same star. The only movement necessary to bring the star to the centre of the bundle should be a rotation. Once it has been correctly centered, a check can be made by going back 300 arcsecs Northwards to find the star still centered on the large bundle.

If the star cannot be found on the North bundle there are two possible explanations;

* *either the bundle was connected to the wrong hole (try moving the telescope 300 arcsecs in the opposite direction or,*

* *the Cassegrain rotator was not positioned well enough to bring the starplates to within the $\pm 3^{\circ}$ adjustment range of the Optopus adaptor.*

V-d) Automatic Guiding

The autoguiding system installed at the 3.6 m telescope can be readily adapted to the Optopus video signal, by modifying the relevant adaption parameter in the autoguide software to "5". This should be done by the night-assistant via the controlroom terminal.

To set up the autoguider, the fictive autoguide crosshair is brought into coincidence with one of the Optopus guidebundle crosshairs on the TV monitor (which can be readily visualised by switching on the He or Ar calibration lamp), and the telescope is then switched over to autoguide control.

The presence of the second guidestar on the monitor will not disturb the autoguider provided the 'image analysis region' of the guide software is not excessively large.

V-e) Calibration Exposures

The Optopus control software contains a self-explanatory menu, of the same standard as used on other ESO instruments, and can be used for defining any desired combination or sequence of calibration lamp exposures. It has been found in the past that with the CCD detector #3, the following typical exposure times were needed with grating #7 (114 Å/mm) in the wavelength region from 3800Å to 5300Å, when using the white calibration screen of the telescope;

* White (quartz-halogen) flat-field lamp :	60 seconds
* He spectral calibration lamp :	24 seconds
* Ar spectral calibration lamp :	24 seconds

These exposure times are given only as an indication, and will vary with different gratings and spectral ranges.

If the user wishes to reduce his data with a well calibrated spectral response curve, this can be achieved by exposing some, or all of the fibres simultaneously on a defocused image of a bright standard star. Experience has shown that typically a 10 minute exposure on a 4th magnitude (v) star will give satisfactory results.

A special starplate is kept in the instrument storage case for this purpose, enabling the fibres to be plugged into a tightly packed ring, surrounding a guide bundle, situated at the plate centre.

The calibration exposures should be made at the beginning of the night, and should ideally be preceded by several "twilight" fibre-calibration exposures for comparison of the relative fibre transmission efficiencies. This procedure enables the calibration starplate to be prepared during the afternoon, thus avoiding an unnecessary wastage of darkness time (since the tightly packed bunch of fibres will require far more time for connector insertion than with a normal starplate).

The procedure followed in order to align the fibres correctly with the standard star is as following;

- *Point the telescope to the coordinates of the reference star,*
- *Guide the telescope exactly onto the star, using the TV monitor,*
- *Defocus the telescope (in either direction) until the secondary mirror shadow in the observed pupil image becomes a little larger than the acquisition area of the large guidebundle,*
- *Begin the exposure,*
- *Correct the telescope tracking whenever the bright part of the defocused image is seen to move onto the guide-bundle (the TV gain must be set appropriately).*
- *Refocus the telescope when the exposure is completed.*

An inconvenience of this technique is that the defocused (pupil) image exhibits many dark zones, and that it is furthermore difficult to be sure that all of the fibres are illuminated by the pupil image. The latter (tracking) difficulty can be somewhat reduced by selecting a standard star which will be able to be observed at a small zenith distance (ie less than 30 degrees). It generally occurs that some of the fibres are inadequately illuminated.

The standard star exposures may NEVER be used to compare the fibres in relative transmission efficiency.

VI MISCELLANEOUS

VI-a) Use of Optopus with the PCD F/1.9 Camera

In december 1985 Optopus was used by two observers with the PCD F/1.9 dioptric camera (instead of the usual Schmidt reflector camera). At the expense of a reduction in the number of fibres (10 less) and the spectral range (24% less) available, an appreciable gain in sensitivity ($\lambda\lambda$ 3600 to 6100Å) was achieved with the dioptric camera by virtue of the absence of a central obstruction (which, in the case of Optopus + Schmidt camera, can cause vignetting losses of up to 50%). Vignetting losses are worsened when an optical fibre is used to transmit the input light, because the fibre tends to partially fill the otherwise dark secondary mirror 'shadow' in the input beam pupil plane (a phenomenon referred to as 'focal-ratio degradation'). This problem can be considerably aggravated whenever a fibre input beam is misaligned due to imperfect input optics (microlens).

With the F/1.9 camera each fibre is projected onto the detector with a monochromatic image size of 90 µm (3 pixels), and fibres #9 through to #45 are detected by the CCD. An on-detector binning factor of 2x2 can be implemented as a noise-reduction measure, resulting only in a small (15%) reduction in spectral resolution. A rotational adjustment screw included in the special adaption flange (see following paragraph) allows the CCD to be brought into precise rotational alignment with the dispersive direction of the spectra, thus avoiding the need for post-rotation of the CCD frames by software (see VII-c).

In order to install the F/1.9 camera between the B&C and the CCD dewar, the following components are needed;

* *A spacing ring which adapts the fitting of the camera to the 3.6m B&C.*
* *An outer supporting structure which shields the camera and provides a rigid attachment for the CCD dewar.*
* *A 2mm thick silica window for the dewar, to enable the shorter F/1.9 back-focal distance to be compensated for.*
* *A special window retainer flange, incorporating a rubber protection ring needed to protect the F/1.9 camera field lens from accidental damage.*

The above components are kept together in a separate wooden case in the Optopus storage room at the 3.6m telescope. The Opticians at La Silla are familiar with the installation of this camera, and a pictorial supplement is available in the Optics office to assist new technicians.

Although the installation of the PCD camera on the 3.6m B&C together with a CCD dewar is a relatively straightforward procedure, it is considerably complicated by the need to exchange the dewar windows (warming up, pumping and cooling down of the dewar takes a minimum of 12 to 15 hours). For this reason it is hardly possible to make a camera changeover more than once during an Optopus observation run. For this reason, when applying for observation time the astronomer should not envisage a change of camera during his allotted period, and should CLEARLY STATE IN HIS 'OBSERVING TIME APPLICATION' WHICH CAMERA IS REQUESTED. The PCD camera may not necessarily be available, due to its planned use with the PCD, or to various other technical reasons.

If a change from PCD to Schmidt camera is required during an Optopus run, the same 2mm dewar window may be kept, PROVIDED an additional 1mm spacer ring is inserted, INSTEAD OF THE 2mm WINDOW RETAINER FLANGE, between the dewar and the Schmidt camera field-lens support flange.

VI-b) Storage of used Starplates

Once the starplates have been used, they should be stored in their shipment boxes together with the Optopus storage boxes at the observing floor level of the 3.6m telescope.

The astronomer may not normally keep his starplates as a souvenir! In the case of unused starplates, which may be needed for future observations, these should be kept by the astronomer (ie sent back to his home institute).

VI-c) Care and Cleaning of Optopus Components

Like most instruments, Optopus has some components which can be easily damaged if they are mishandled. The areas in which particular care should be taken are described below.

* *Fibres : Although the optical fibres are shielded by protective cables, they could be broken if the cables are sharply bent or placed under undue stress. The connectors should never be unplugged from starplates by pulling with excessive force on the cables.*

* *Microlenses : The microlenses, which project slightly beyond the ends of the connectors, can be damaged if they are accidentally scratched against a hard surface. For this reason also, the fibre connections and disconnections should be made at the telescope ONLY by a trained person. Plastic protective caps are provided for the microconnectors, and are to be used during storage and transport of Optopus.*
  The microlens ends may be cleaned with a suitable optical tissue and ethyl alcohol.

* *Fibre Output Slit : The output slit is protected by a window which is glued in place. To prevent accidental damage to this window, it is surrounded by a hard plastic end-cap whose upper surface is just higher than that of the window. If cleaning should be necessary, this can be done with an optical tissue and alcohol (if necessary), but NEVER WITH ACETONE (!) as this solvent will partially dissolve the protective plastic, producing a semi-opaque smear across the window!*

* *Collimator : As mentioned in (IV-b) the collimator contains a high expansion glass, and should therefore be protected from thermal shocks. The protective end caps provided for both ends of the collimator should be mounted in place at all times whenever it is being transported or is in storage. A solid wooden storage case is provided for the collimator and focusing unit.*

* *Guide Bundles : The coherent fibre bundles are assembled within protective swan-neck tubes, intended to limit bending and to prevent any breakage of the bundles. Excessive force could nevertheless lead to damage of the bundles or to their jointed connector ends.*

  Care should be taken when connecting the guide bundles to a starplate, to avoid damaging the assymetric orientation rings or crossing the thread of the clamping collets If the thread is badly damaged, the guide bundle can no longer be correctly fixed to the starplate guide inserts. Whenever Optopus is not in use, the guidebundles should be stored with their protective metallic caps. When the instrument is being used on the telescope, loss of the caps can be avoided by screwing them onto the specially provided threaded studs on the camera support structure.

VI-d) Storage of the Instrument Components

As mentioned in VI-b, a robust storage case is provided for the F/3 collimator. It is preferable to store the collimator assembled together with its adaption flange, in order to reduce the work required in mounting these units for the following Optopus observation run.

The fibre component of Optopus is kept in a separate metal case, in which the guide bundle cables may also be stored.

The TV camera has a small special case in which it should be stored to protect it from shocks.

These cases can be stored together with the Optopus adapter flange, the 'test' starplates and the electric cables, in the large wooden case which was used to transport the instrument to Chile.

VII OPTOPUS DATA REDUCTION WITH IHAP

VII-a) Introduction

At the time of writing (April 1986) the reduction of Optopus spectra is possible only with the ESO IHAP system, run on an HP1000 computer. The frame reduction operations mentioned in the following are specific to the IHAP data reduction system, and may in the future be modified or replaced by more powerful algorithms. This is to be hoped for operations suh as "PSADD" which at present suffer from some shortcomings.

It is envisaged that new commands, which could be used to reduce Optopus spectra (even though they are not dedicated to this particular instrument), will be available in the ESO MIDAS environment by the end of 1986.

As mentioned in the introduction to this Manual, Optopus is not suited for accurate spectrophotometry; this is true as much from the data-reduction as from the instrumental point of view. It is therefore not the purpose of this chapter to provide the user with a single unequivocal formula for data reduction, but rather to explain the use and shortcomings of the IHAP commands designed for handling Optopus frames, and to bring to light some other procedures which have proven to be useful and in some cases more accurate than the special 'Optopus' commands.

In order to clarify the examples given in the following paragraphs, some abbreviations are adopted here to represent the various raw CCD frames which may have been recorded at the telescope :

#OBJ	*- Original object frame*
#WLFF	*- White lamp flat-field frame*
#TSFF	*- Twilight sky flat-field frame*
#SSFF	*- Standard star flat-field frame*
#SKB	*- Sky background frame*
#DK	*- Dark frame*
#HEAR	*- Helium Argon calibration frame*

Wherever relevant, the various frames and line files produced by IHAP operations are assigned an abbreviated file name such as #OBJ2, where;

R90,#OBJ1 ...... #OBJ2 (R90 of #OBJ1 produces #OBJ2, etc.)

As in all CCD reduction work, an estimate of the (dark) electronic bias (*) contribution must be subtracted from each raw frame.

** In 1985, the mean dark signal was equivalent to 186 ADU for the ESO CCD #3.*

The "dark corrected" frames are indicated here with the numerical subscript '1', eg;

#OBJ - #DK = #OBJ1

In the following, it is assumed that the raw CCD frames have been obtained with the spectra displayed vertically (ie with the spectrograph dispersion parallel to the longest edge of the CCD). As the algorithms described below are applicable to HORIZONTALLY displayed spectra, it is assumed that all dark-corrected frames have been rotated by this amount as in the example given below;

R90,#OBJ1 .... #OBJ2

VIIb) Radiation Event Deletion

The most effective way of removing radiation (often refered to as 'cosmic') events from CCD frames is to compare 2 or 3 exposures made under identical conditions, using the IHAP command FCOMPARE. Ideally, such exposures should have been made sequentially, with the telescope pointing in (nearly) the same direction.

If only single frames are available, the RBLEMISH command can be used locally, taking care to carefully define the window over which this function determines its mean value calculation. This is particularly important with Optopus frames since the spectra do not have a uniform profile in the direction perpendicular to dispersion (the middle pixel line contains more energy than the outer lines).

In practise, since the energy of some radiation events is quite small, it can become extremely difficult and tedious to IDENTIFY and filter even most of the events present on a single CCD frame. The identification and smoothing of these events can be simplified by creating a 'mask', i.e. the ratio of the original frame with a filtered version of itself. A frame filter which has proven quite effective for this purpose is;

FILTER,#OBJ2,MD,1,4,50 .... (#OBJF)

The mask (#OBJM), given by the ratio : #OBJ2/#OBJF, will clearly show the locations of almost all cosmic events and peaked spectra, if suitable colour table and frame 'CUT' levels are chosen. The mask can now be locally 'doctored', by use of the RBLEMISH function and the RAMTEC cursor, to remove the 1 (or sometimes 2) pixel cosmic events, without affecting the remaining information. Function parameters proven to be effective are shown in the example below;

RBLEMISH,MD,1,7,1.5 .... (use Ramtek cursor)

where the last parameter must be adjusted according to the relative noise level of the mask.

As the line summation algorithm PSADD described in VII-d is generally performed over several pixel lines, it can be equally important to remove radiation events situated at the weak edges of the spectra of interest. The locally filtered mask (#OBJMF) is then used to restore the original frame without radiation events;

PFUNCTION,#OBJMF,OBJF,X .... #OBJC (cleaned)

VIIc) Correction of Residual Image Rotation

If the detector has been sufficiently well aligned, as described in (IV-e), it will be unnecessary to rotate the frames. In general, a residual rotational alignment error of one pixel or less can be tolerated and will have little effect on the extracted 1-D spectra, PROVIDED the latter are obtained by adding a sufficiently large number of frame lines (see VII-d) to include all pixels contributing significantly to each spectrum. A greater number of summed lines will increase the noise in the extracted spectra.

If a rotation of the frames is considered necessary, it should NOT be done using the ROTATE,#OBJ..... command, as this algorithm can introduce unnecessary noise into the rotated Optopus images. The reason is that 'ROTATE' uses an algorithm which calculates, for each destination pixel, a bilinear interpolation from the 4 nearest pixels of the old frame. As Optopus frames are by their very nature highly non-uniform in illumination, they are prone to considerable error generation when handled with this algorithm, as can be demonstrated by rotating a frame forwards by a given angle and then backwards by the same amount.

A prefered procedure is to use the distortion correction algorithm (DISTORT) often used to straighten IDS image tube spectra, without the use of interpolated values. In the case of Optopus frames, the distortion is a linear tilt combined with a negligeable degree of camera distortion, and it is sufficient to use a 1st order polynomial fit to define the needed correction. The use of the DISTORT algorithm is demonstrated by the following example :

1) KDISP,#OBJC	
2) KLOOKUP	*- use ramtek to optimise colour display.*
3) LTDISTORT	*- use ramtek to identify the middle of a chosen spectrum at 6 or 7 different wavelengths.*
4) TPOLY,1	*- the best linear fit is shown, and kept in an internal table.*
5) DISTORT,#OBJC	*- this operation lasts several minutes, (and produces #OBJD).*

Line 5 of the above example can then be applied to all of the frames #...2 or #...C implied in the foregoing paragraphs, provided they were obtained under identical grating and grating angle conditions.

VIId) Conversion to Line Spectra

In converting an Octopus frame into a set of line spectra (i.e. one per fibre) it is necessary to sum, for each spectrum, a suitable number of lines (typically 3 to 5) from the frame. For any particular pixel line associated with a given object spectrum, the decision whether to include it in the summed pixel lines should be based upon a comparison of its intensity relative to that of the other associated lines; clearly, a relatively feeble pixel line will (by virtue of its readout noise contribution) only help to reduce the SNR of the other summed pixel lines. This can be understood more easily by inspecting Fig. 5, which shows a cut across part of an Optopus frame. With the aid of SNR calculations, or less rigorous visual estimates, one would choose to sum either two or three of the pixel lines - depending on which spectrum was in question. Obviously, this selection would involve quite some time and concentration in noting down the pixel lines to be associated with each spectrum, and would complicate the subsequent calibration procedure with respect to that implied by summation of a fixed number of pixel lines in every case.

Although the above procedure should be adopted if an optimal SNR and intensity calibration is to be obtained for each spectrum, the following simplified method can be used to save time if calibration accuracy is uncritical. The algorithms used are PPOSITION and PSADD; The first enables the most intense pixel line of each spectrum to be identified and stored in an internal table, and the second command sums a specified number of pixel lines centered on each of these lines. A well exposed flat-field frame should be used to identify the most intense pixel lines, as shown in the following example;

```
XADD,#TSFFD,X250,X260,ME               ............... (#TSCUT)
PPOSITION,#TSCUT,,(threshhold)         ........(internal table)
```

where the threshhold is chosen to avoid identifying noise as spectral lines.

Finally, this table can be used to convert all frames obtained under similar conditions into line spectra, using the command PSADD, as shown in the example below;

```
PSADD,#OBJD,5                          ............. (#OBJEXT)
```

Here, the '5' in the last field means that the spectra will each be summed up over 5 pixel lines, centered on the values stored in the internal table generated from TSCUT.

The results, when displayed using KDISP, #OBJEXT etc., are seen as a compact group of "n" horizontal lines, where "n" is the number of fibres recorded on the CCD frame.

VIIe) Correction for Fibre-slit Misalignments

The necessity for this alignment procedure arises firstly from the fact that the fibres are not aligned in a perfectly straight line (the scatter corresponds typically to less than 0.25 pixels), and secondly because the slit alignment procedure described in (IV-e) will probably leave a small angular misalignment.

A table of the X-misalignments is first created from an appropriate extracted HeAr calibration image using the command PTRACK, which follows defined calibration lines from one spectrum to the next in a direction approximately perpendicular to the dispersion. This command is written in the form of the following example...

PTRACK,#HEAREXT,X161.76,7,X325.39,7 ... ... etc.

where the 'X' values identify the centres of up to 4 chosen calibration features in the first scan line. These coordinates can be obtained using the SLCENT or even the COORD command.

The fields occupied here by a '7' indicate the pixel window within which each respective feature is to be tracked. The PTRACK algorithm determines, for each spectrum (ie. for each scan line of the HEAR6 file) the mean X-shift of the spectral features within their defined windows, and stores these values in an internal table. It is very important to ensure that the HeAr features are correctly identified on every spectrum, and that the displayed x-offsets in a given spectrum are similar for each feature. This should ensure that the maximum differential wavelength offset between any two spectra does not exceed one pixel, and that a single wavelength calibration table (derived from one spectrum by the usual method) can later be applied to ALL of the realigned spectra derived from PALIGN,... (see below).

All the 2D images obtained under the same conditions of grating and setting angle can now be realigned using the internal table (produced by PTRACK), with the instructions...

PALIGN,#OBJEXT .... (#TSFFEXT etc.)

ANNEX

a) GRATING DATA - TABLE 6 (A,T)
b) GRATING SETTING and EFFICIENCY CURVES - FIGS. 6 (A,T)

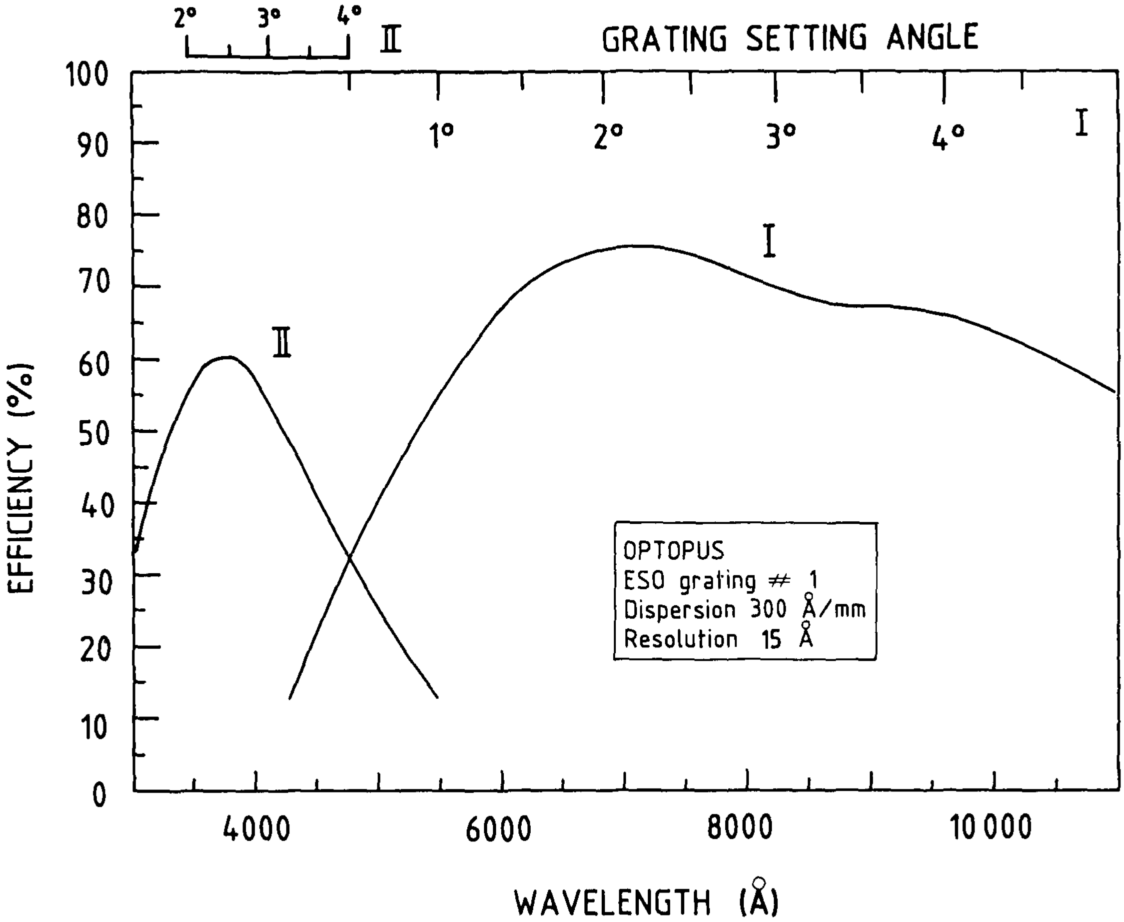
TABLE 6 : GRATING DATA

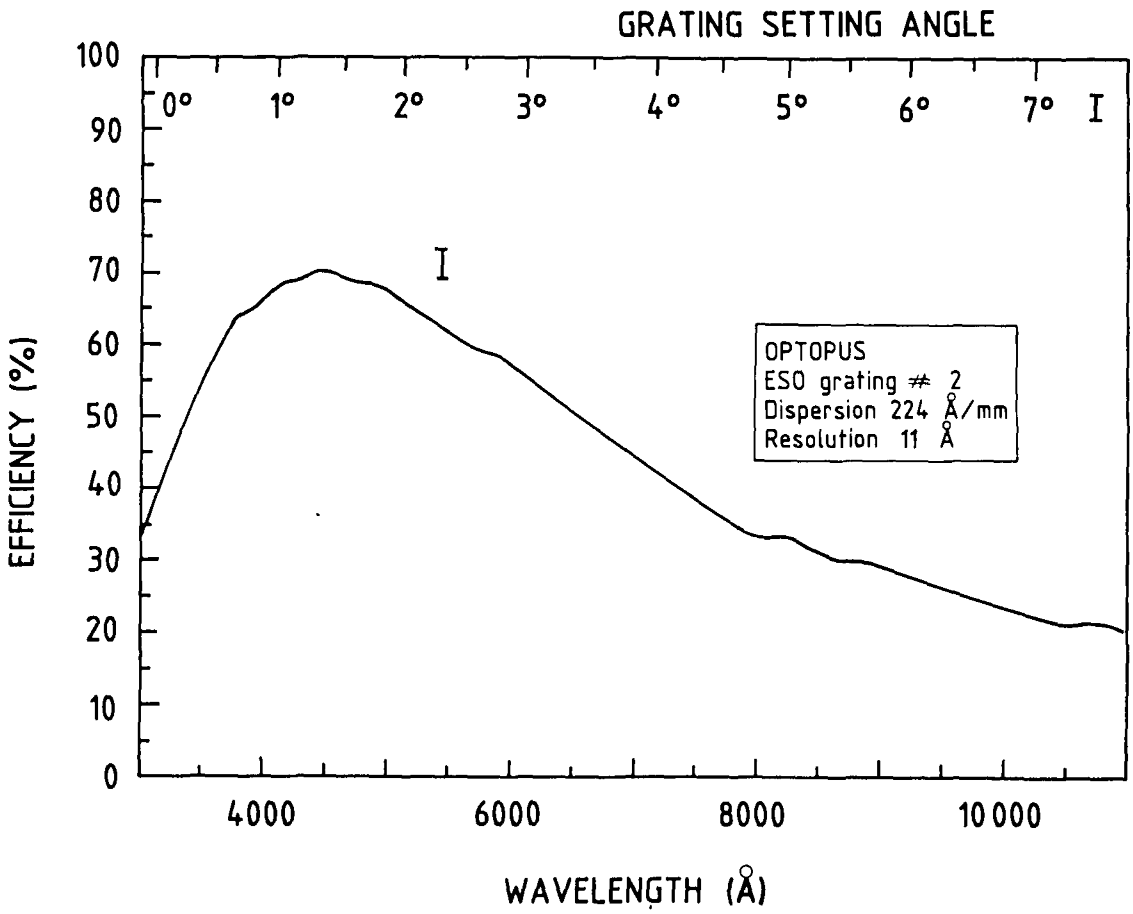
ESO No.	Grooves/mm	Blaze angle	Order	Optopus central wavelength (Blaze)	Grating setting^Δ constant for B+C	Dispersion
#	n	ϑ_B	k	λ_B	K $(x10^{-3})$	Å/mm
1	225	5°20'	I	7329	0,728	298
			II	3664	1,47	149
2/15	300	4°18'	I	4434	0,974	224
3/17	400	9°44'	I	7498	1,31	173
			II	3749	2,69	86,5
4/6	600	13°0'	I	6651	1,96	116
			II	3325	3,93	58
5	900	21°10'	I	7117	2,99	78
			II	3559	5,97	39
7/23	600	8°38'	I	4438	1,96	114
8/24	400	4°30'	I	3480	1,30	171
9/18	300	8°38'	I	8870	0,971	228
			II⊕	4435	1,96	114
10/19/28	600	17°27'	I	8870	1,96	118
			II⊕	4435	3,94	59
11/20	1200	36°52	I	8870	4,10	58
			II⊕	4435	8,22	29
12/22	1200	26°45'	I	6654	4,00	59,5
13	150	2°09'	I	4437	0,485	450
14	400	13°54'	I	10654	1,31	172
16/21	400	6°54'	I	5328	1,30	172
25	400	6°30'	I	5020	1,29	172
26	1200	22°12'	I	5585	4,00	58
			II	2793	8,15	29
27	600	11°21'	I	5819	1,95	114

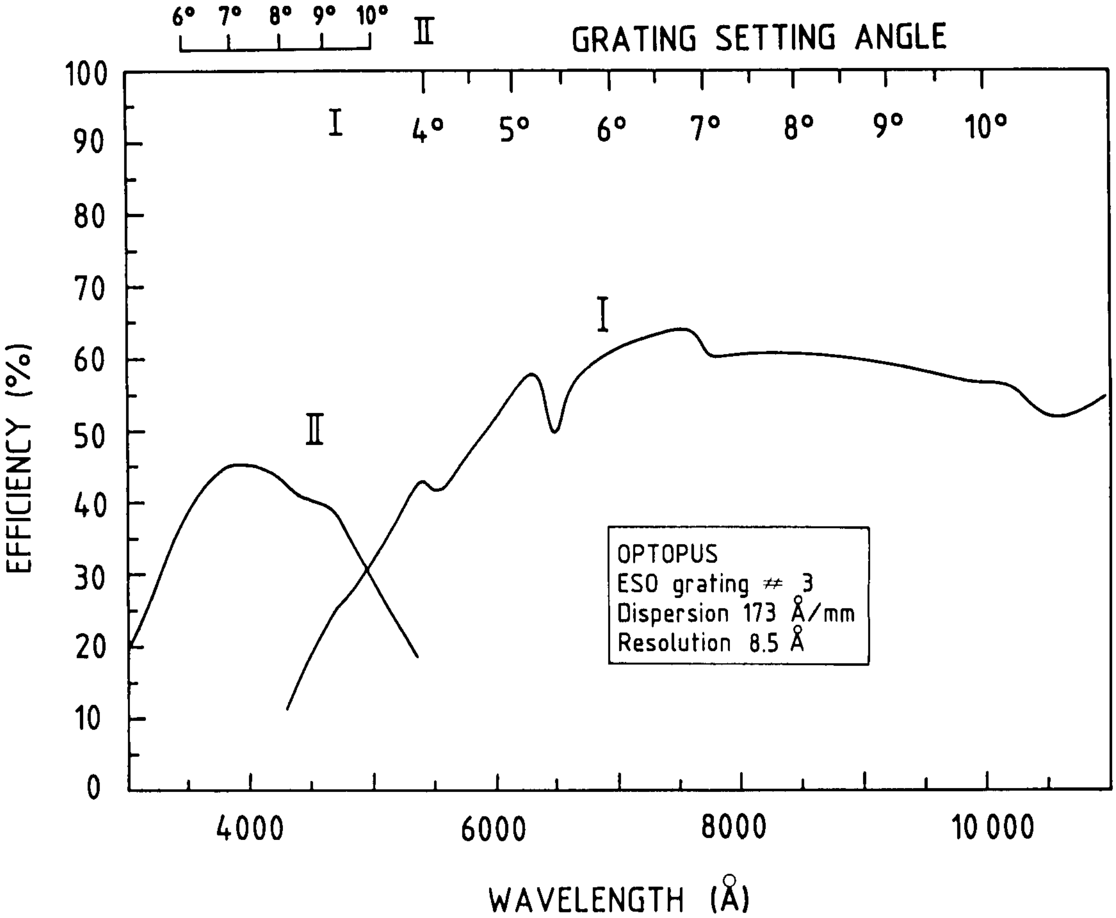
⊕ not recommended

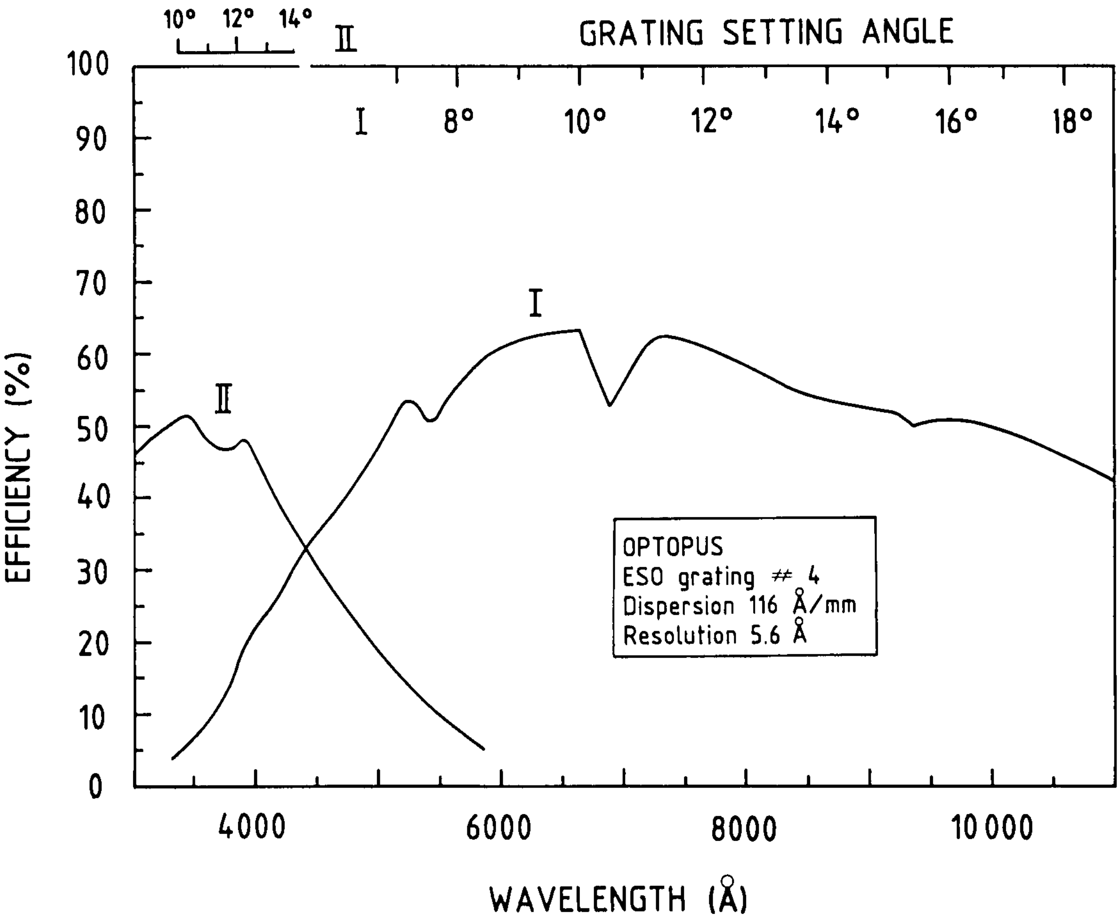
Δ The B&C grating setting angle is closely approximated by $\theta^\circ_{opt}(\lambda) = K.\lambda - 3°$
where λ (Å) is the desired central wavelength.

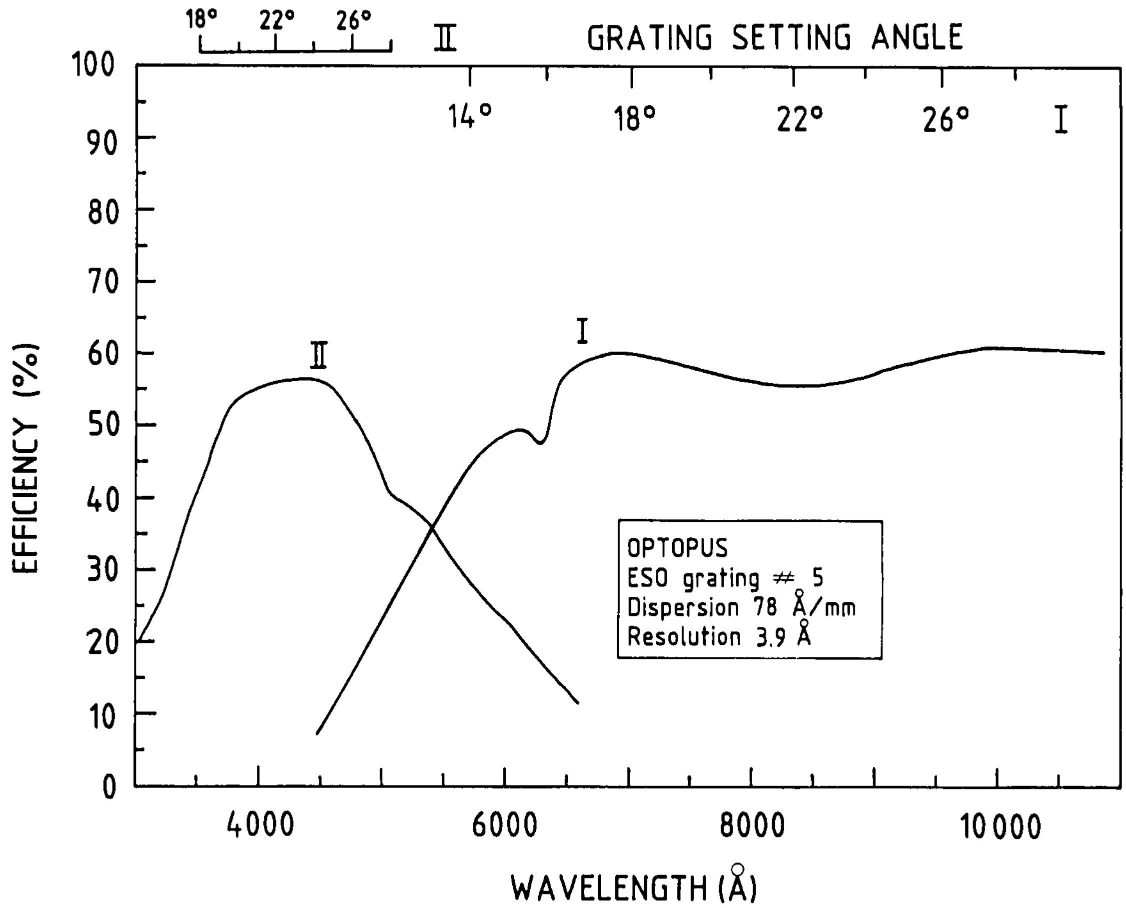
FIGURES 6 : GRATING SETTING AND EFFICIENC CURVES

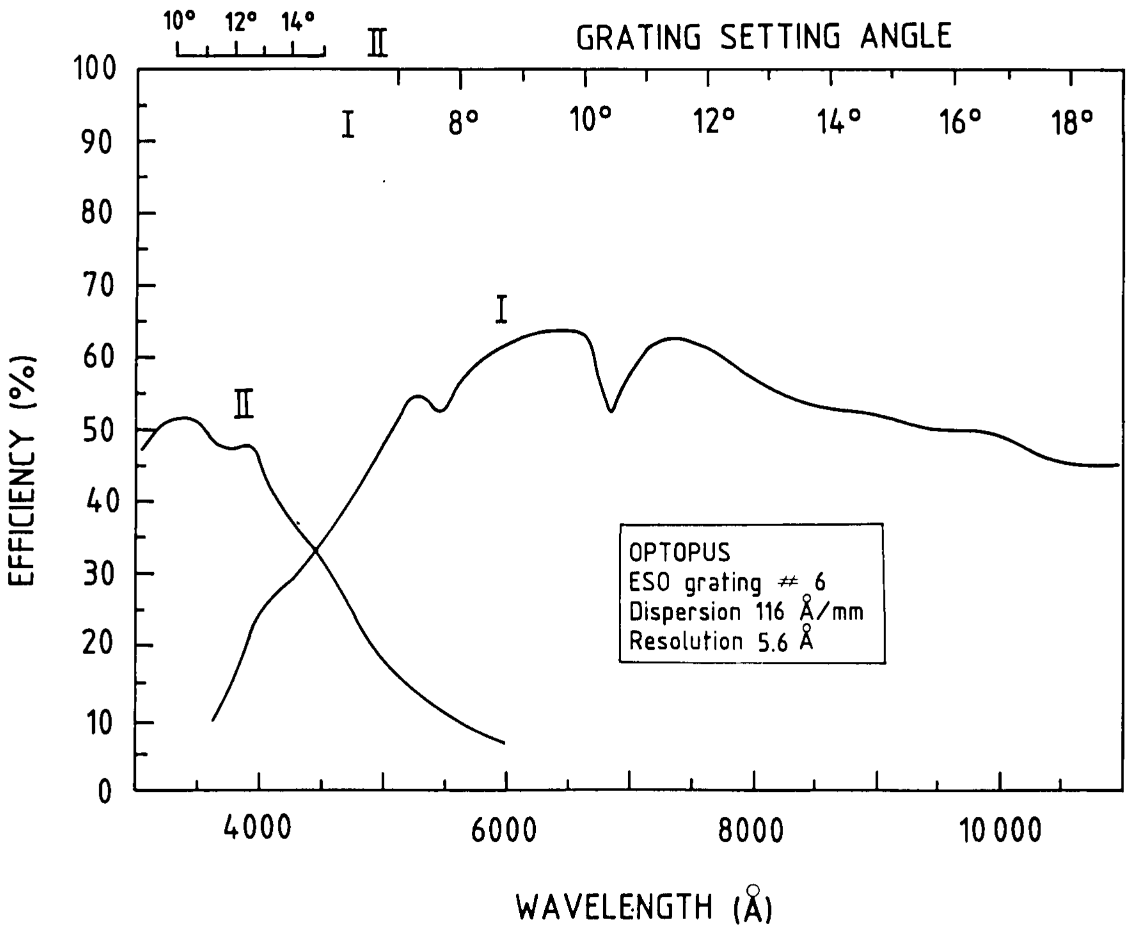

2° 3° 4° II
GRATING SETTING ANGLE
1° 2° 3° 4° I
I
II
OPTOPUS
ESO grating ≠ 1
Dispersion 300 Å/mm
Resolution 15 Å
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
4000 6000 8000 10 000
WAVELENGTH (Å)

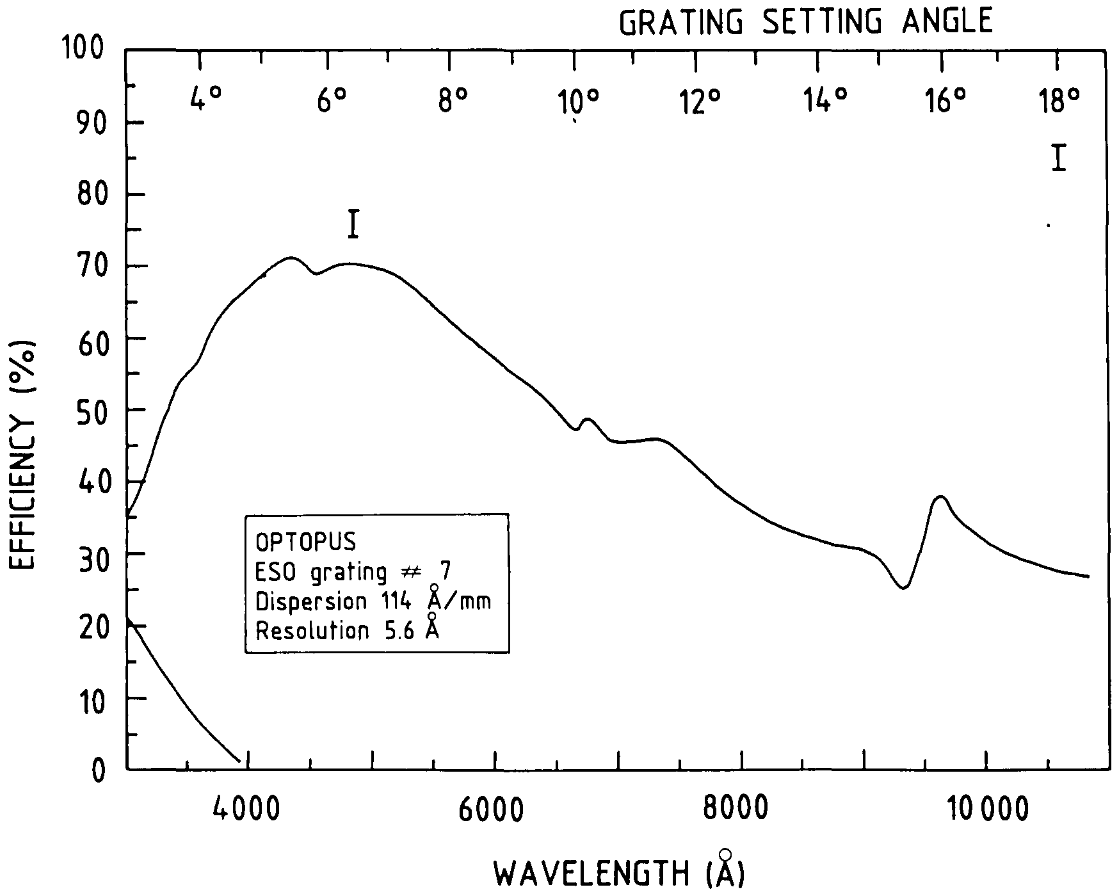

GRATING SETTING ANGLE
0° 1° 2° 3° 4° 5° 6° 7° I
I
OPTOPUS
ESO grating ≠ 2
Dispersion 224 Å/mm
Resolution 11 Å
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
4000 6000 8000 10 000
WAVELENGTH (Å)

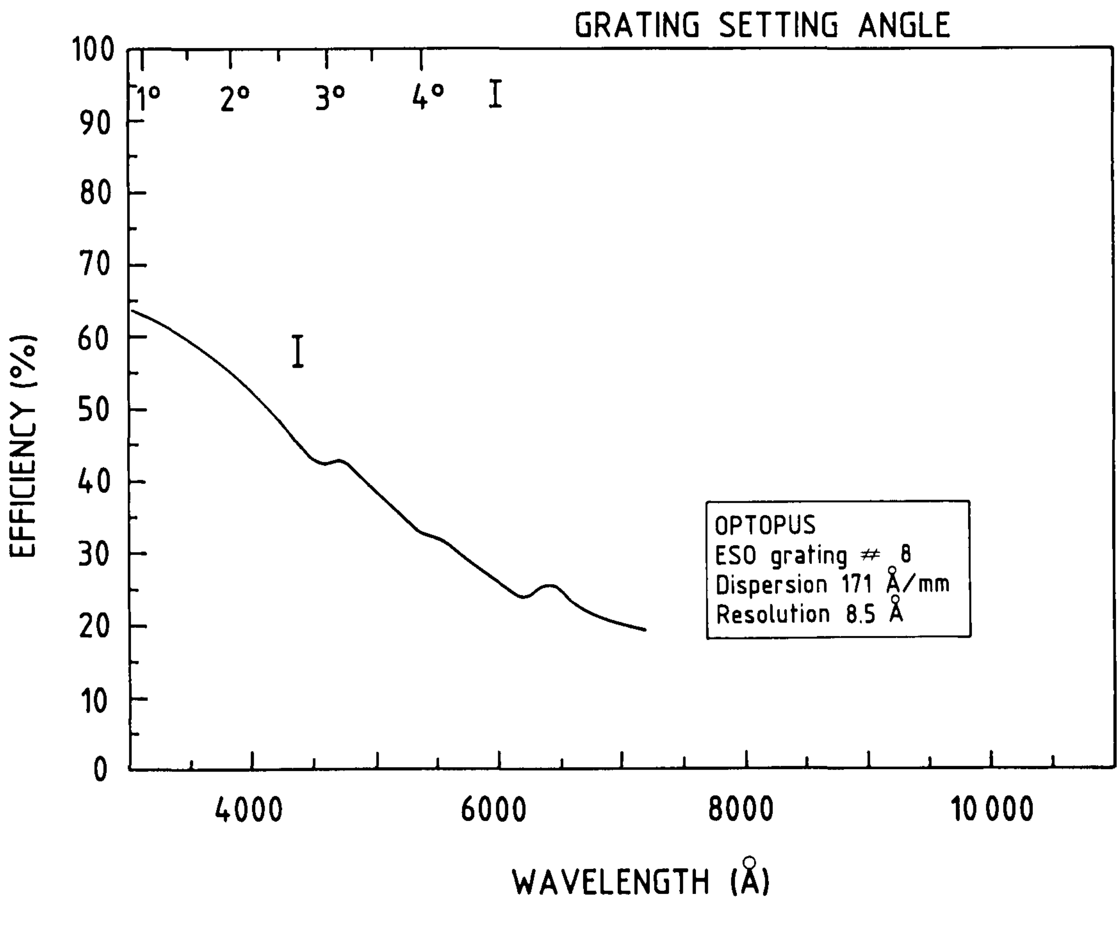

6° 7° 8° 9° 10°
II
GRATING SETTING ANGLE
I
4° 5° 6° 7° 8° 9° 10°
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY (%)
II
I
OPTOPUS
ESO grating ≠ 3
Dispersion 173 Å/mm
Resolution 8.5 Å
4000
6000
8000
10 000
WAVELENGTH (Å)

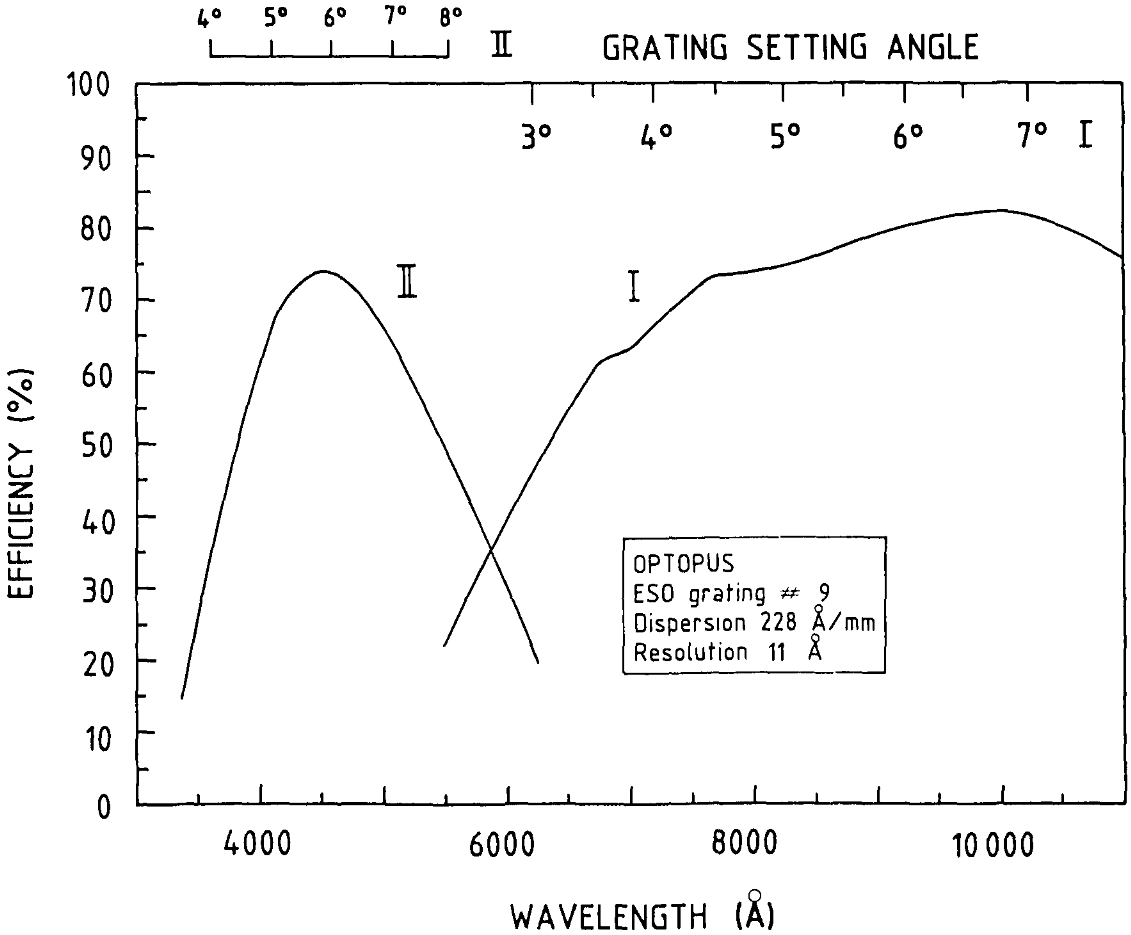

10° 12° 14°
II
GRATING SETTING ANGLE
I
8° 10° 12° 14° 16° 18°
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY (%)
II
I
OPTOPUS
ESO grating ≠ 4
Dispersion 116 Å/mm
Resolution 5.6 Å
4000
6000
8000
10 000
WAVELENGTH (Å)

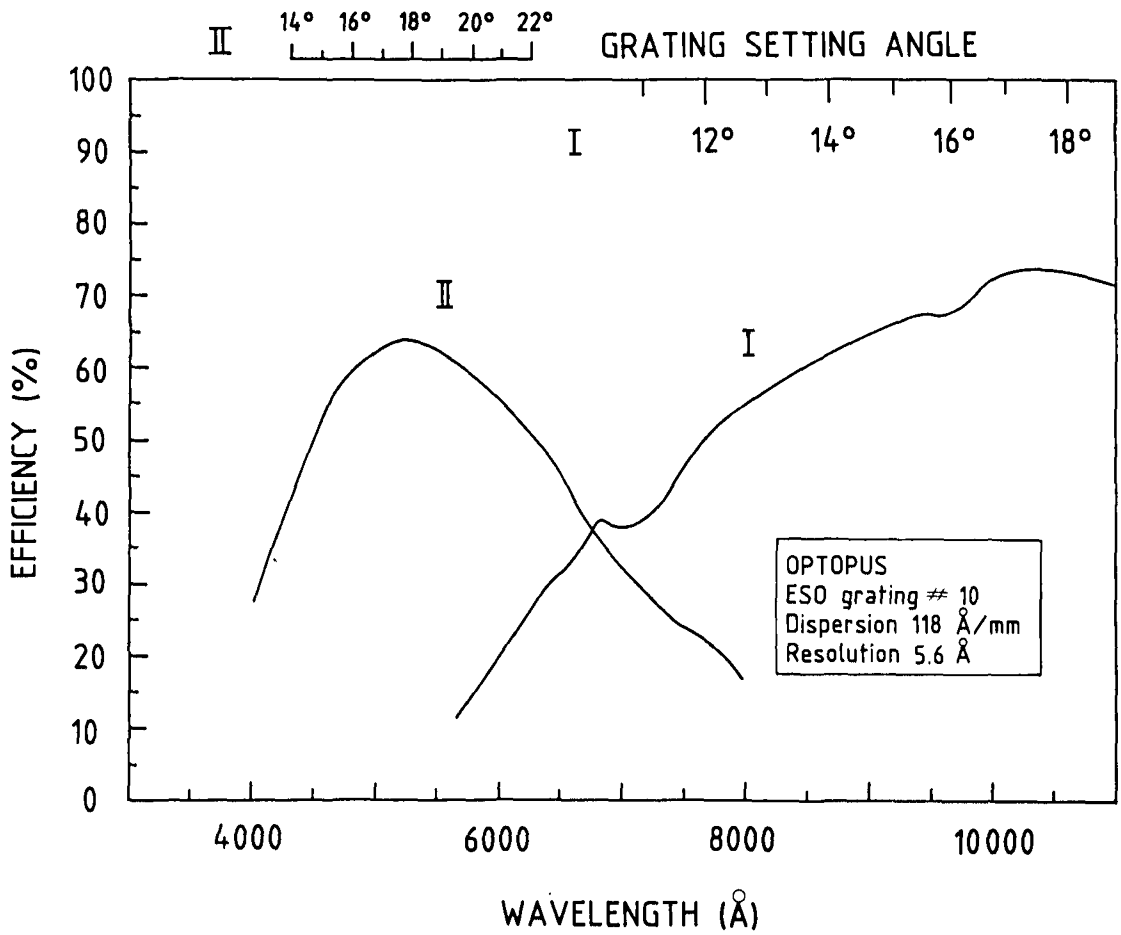

18°
22°
26°
II
GRATING SETTING ANGLE
14°
18°
22°
26°
I
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY (%)
II
I
OPTOPUS
ESO grating # 5
Dispersion 78 Å/mm
Resolution 3.9 Å
4000
6000
8000
10 000
WAVELENGTH (Å)

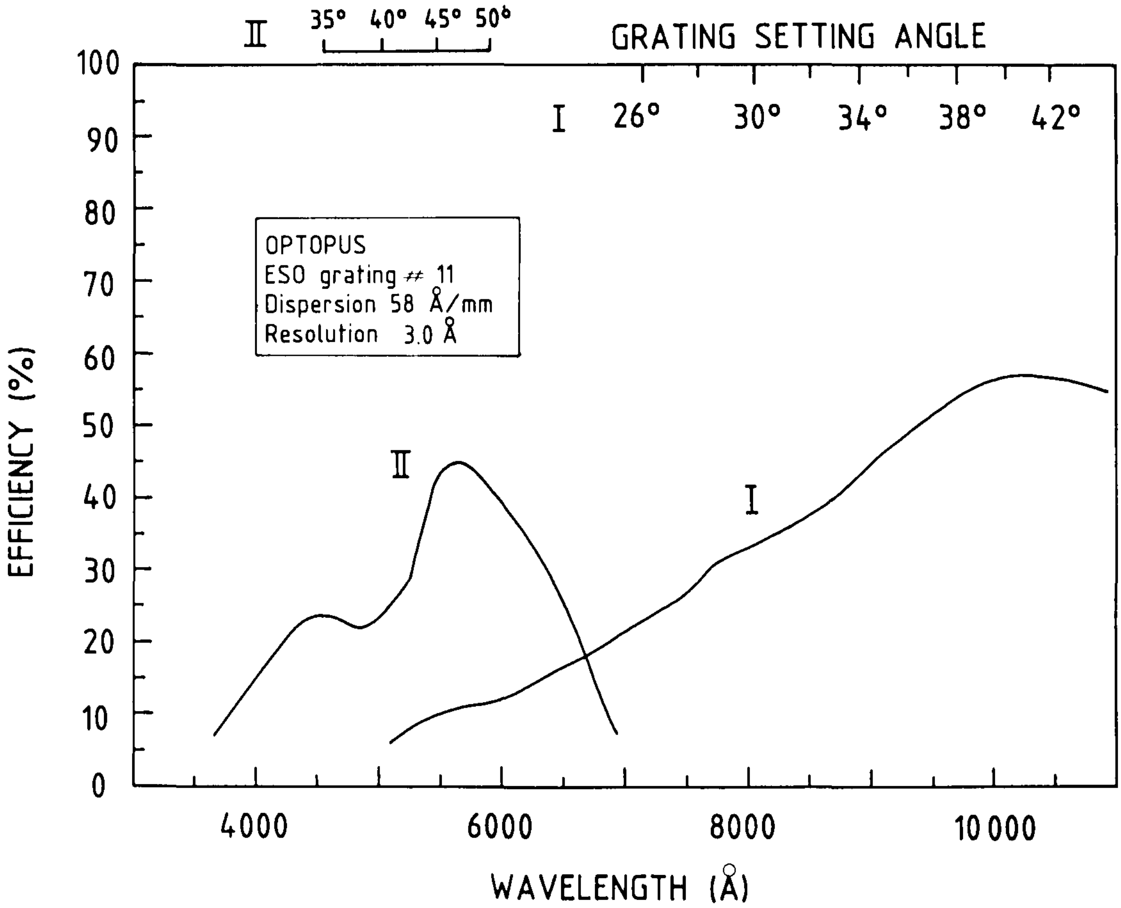

10°
12°
14°
II
GRATING SETTING ANGLE
I
8°
10°
12°
14°
16°
18°
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY (%)
I
II
OPTOPUS
ESO grating # 6
Dispersion 116 Å/mm
Resolution 5.6 Å
4000
6000
8000
10 000
WAVELENGTH (Å)


GRATING SETTING ANGLE
4° 6° 8° 10° 12° 14° 16° 18°
EFFICIENCY (%)
100 90 80 70 60 50 40 30 20 10 0
OPTOPUS
ESO grating ≠ 7
Dispersion 114 Å/mm
Resolution 5.6 Å
4000 6000 8000 10 000
WAVELENGTH (Å)

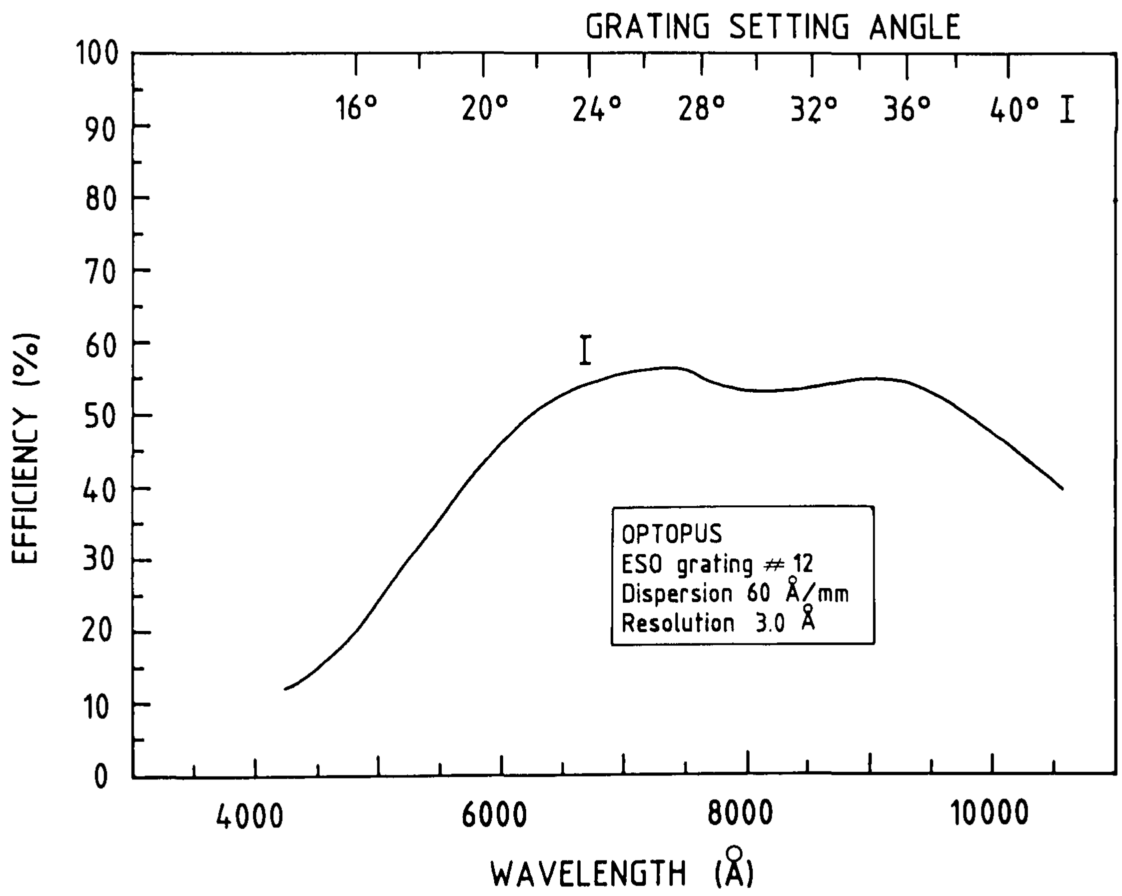

GRATING SETTING ANGLE
1° 2° 3° 4°
EFFICIENCY (%)
100 90 80 70 60 50 40 30 20 10 0
OPTOPUS
ESO grating ≠ 8
Dispersion 171 Å/mm
Resolution 8.5 Å
4000 6000 8000 10 000
WAVELENGTH (Å)


4°
5°
6°
7°
8°
II
GRATING SETTING ANGLE
3°
4°
5°
6°
7°
I
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY (%)
II
I
OPTOPUS
ESO grating # 9
Dispersion 228 Å/mm
Resolution 11 Å
4000
6000
8000
10 000
WAVELENGTH (Å)

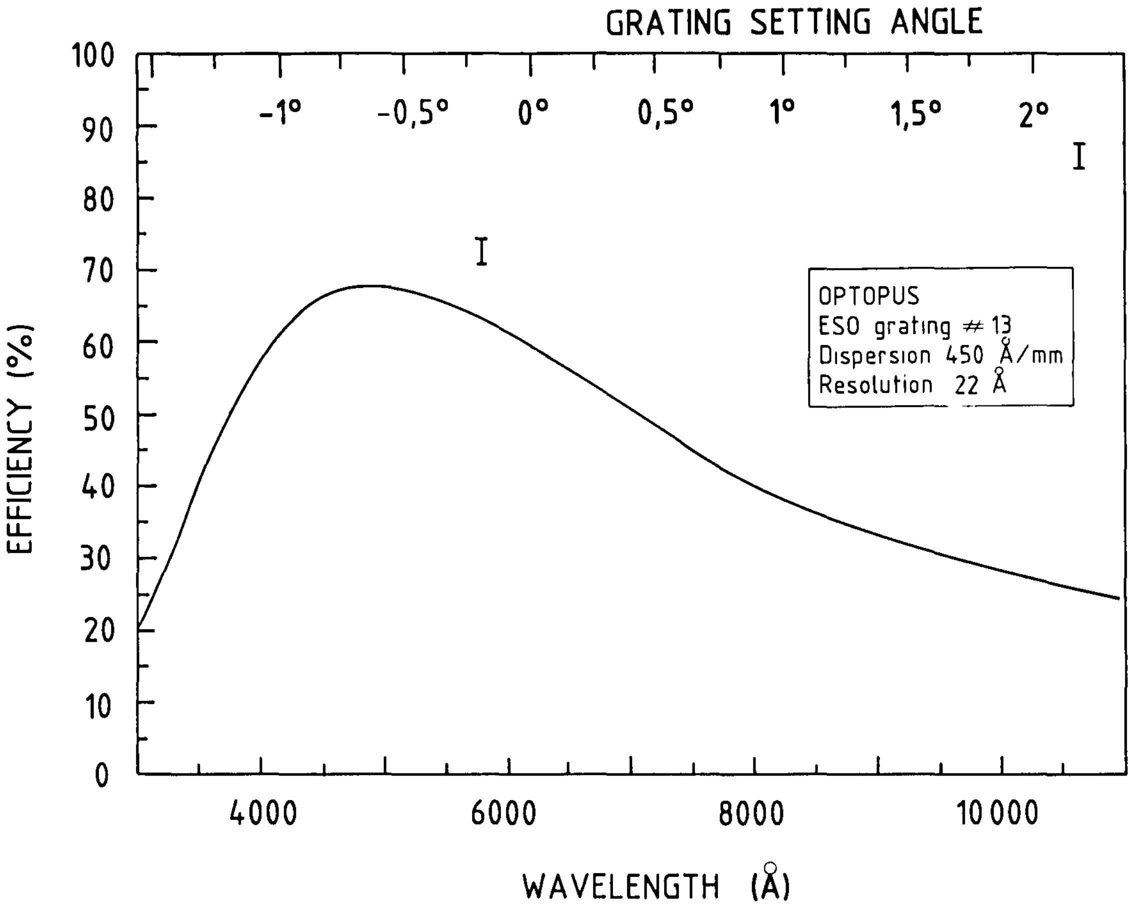

II
14°
16°
18°
20°
22°
GRATING SETTING ANGLE
I
12°
14°
16°
18°
100
90
80
70
60
50
40
30
20
10
0
EFFICIENCY (%)
II
I
OPTOPUS
ESO grating # 10
Dispersion 118 Å/mm
Resolution 5.6 Å
4000
6000
8000
10000
WAVELENGTH (Å)

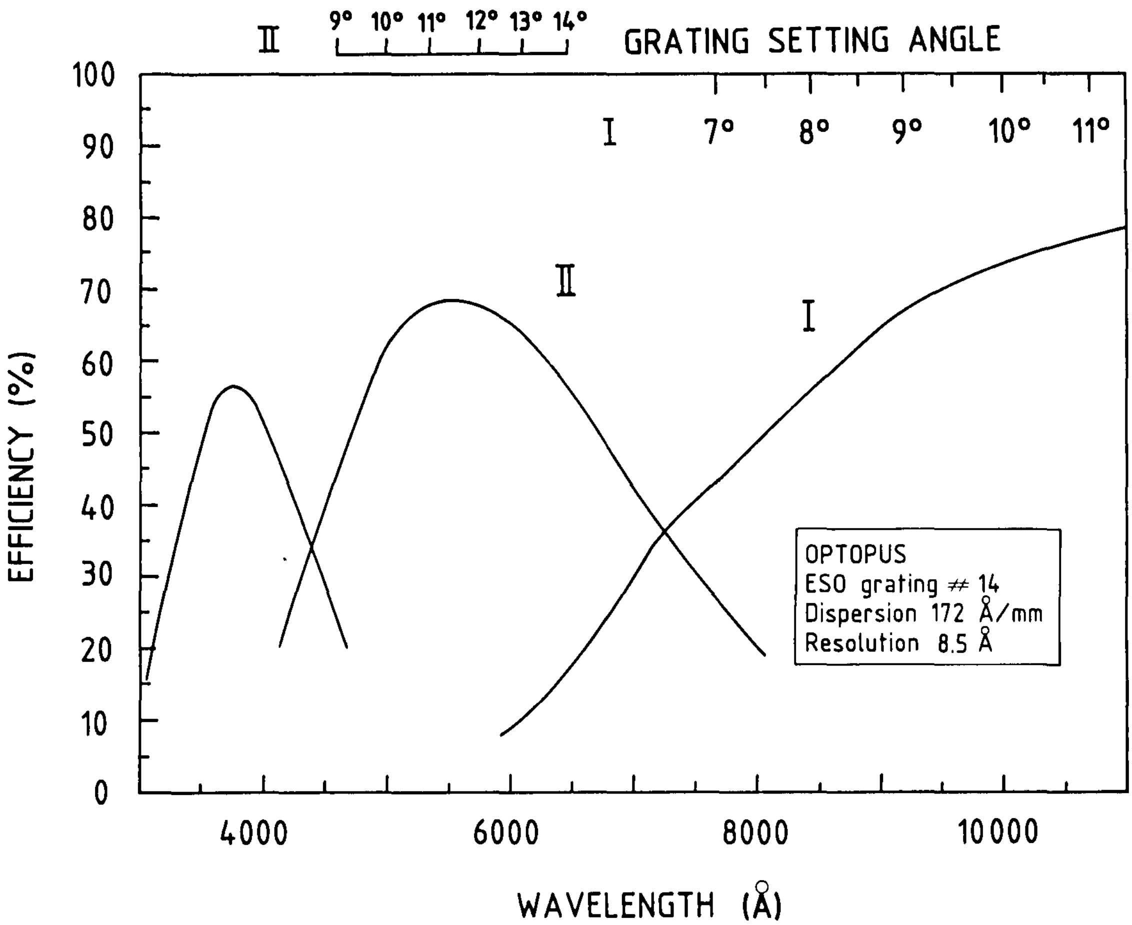


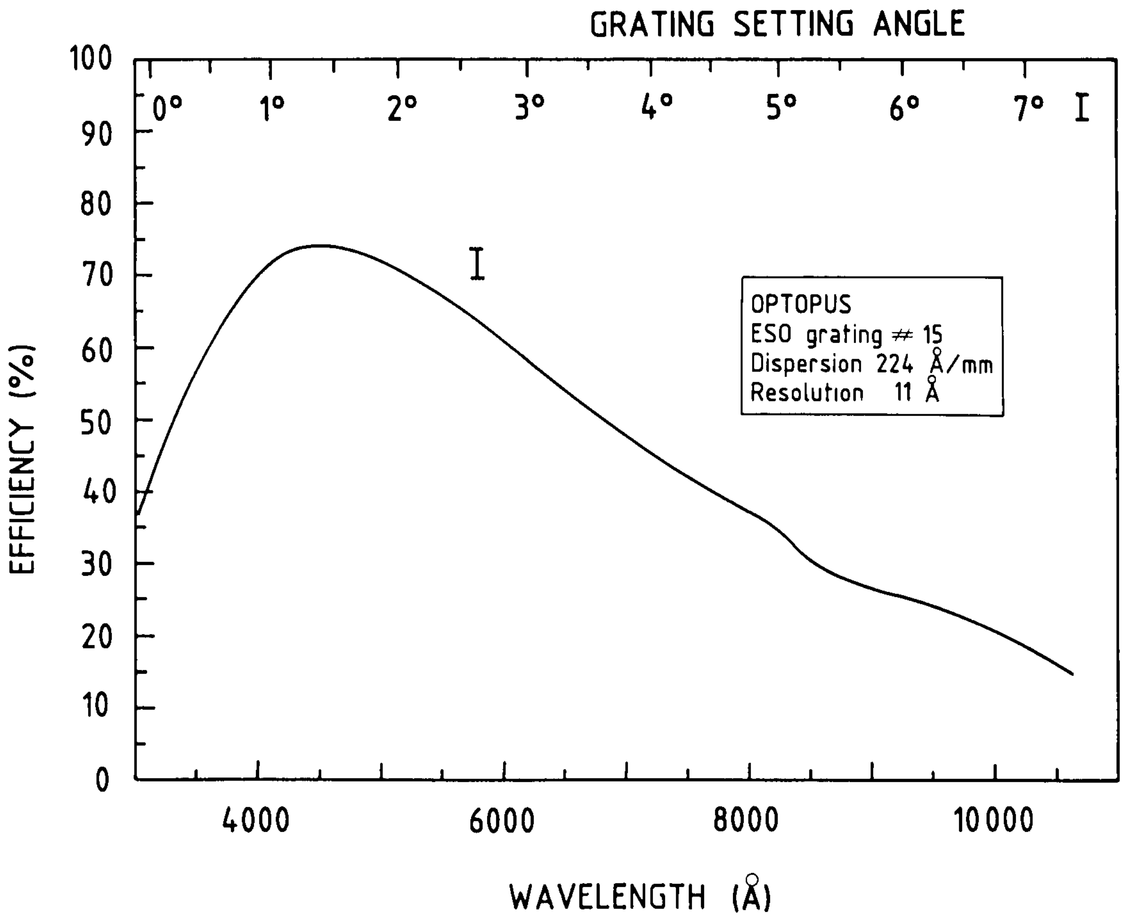
II 35° 40° 45° 50°
GRATING SETTING ANGLE
I 26° 30° 34° 38° 42°
OPTOPUS
ESO grating ≠ 11
Dispersion 58 Å/mm
Resolution 3.0 Å
EFFICIENCY (%)
WAVELENGTH (Å)

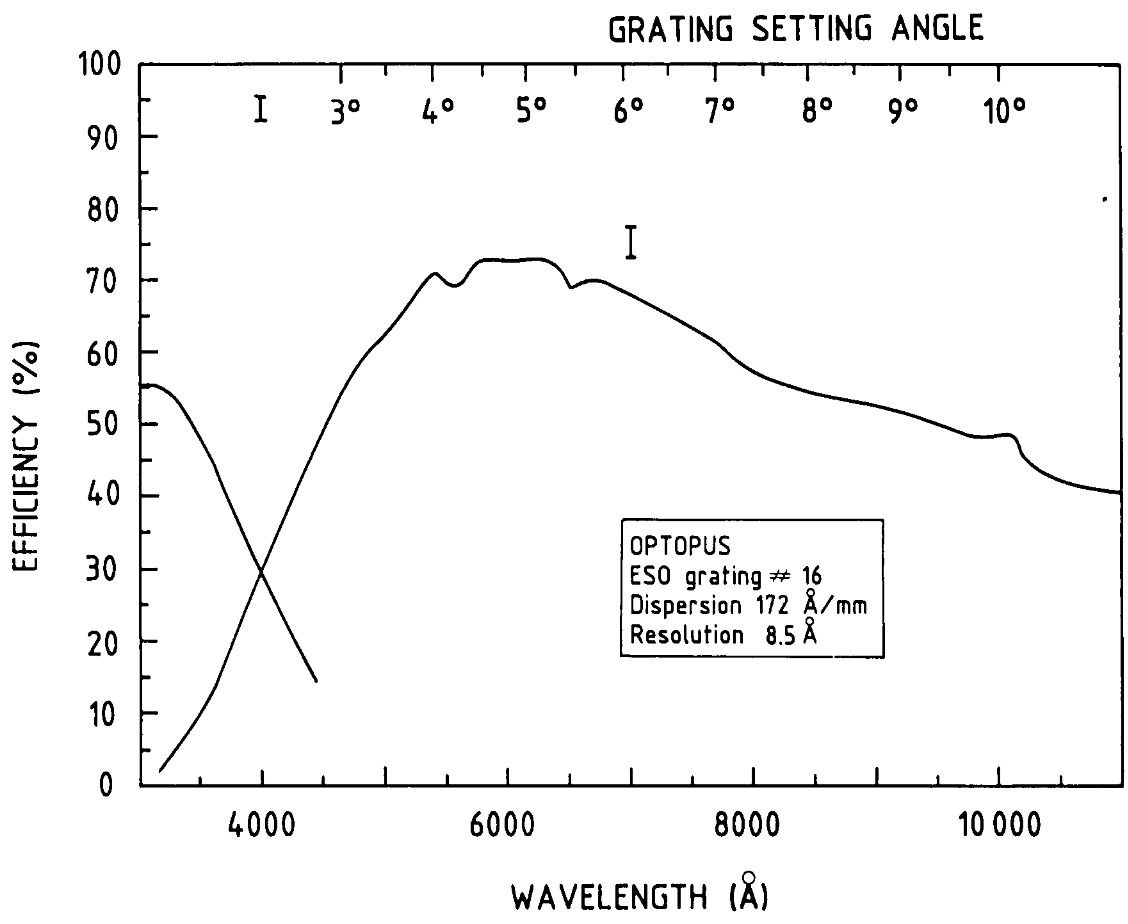


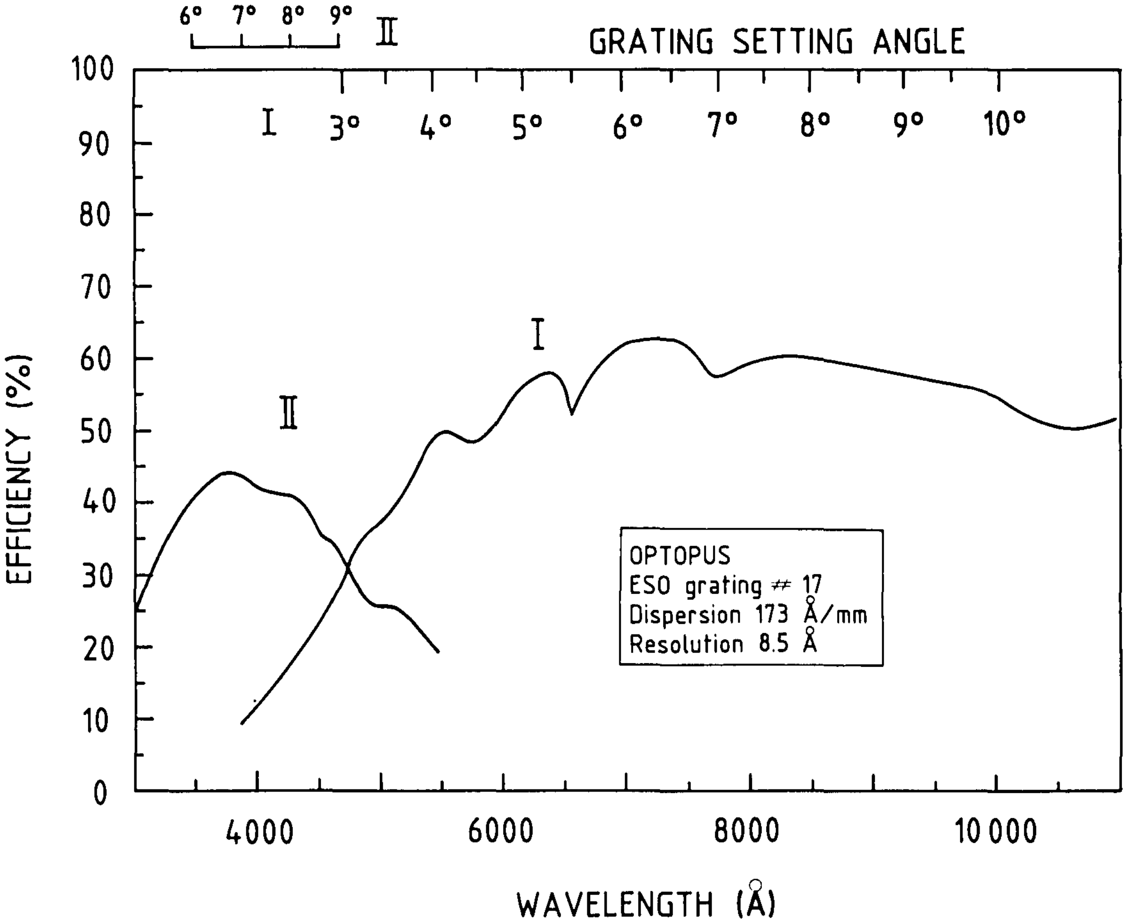
GRATING SETTING ANGLE
16° 20° 24° 28° 32° 36° 40° I
OPTOPUS
ESO grating ≠ 12
Dispersion 60 Å/mm
Resolution 3.0 Å
EFFICIENCY (%)
WAVELENGTH (Å)

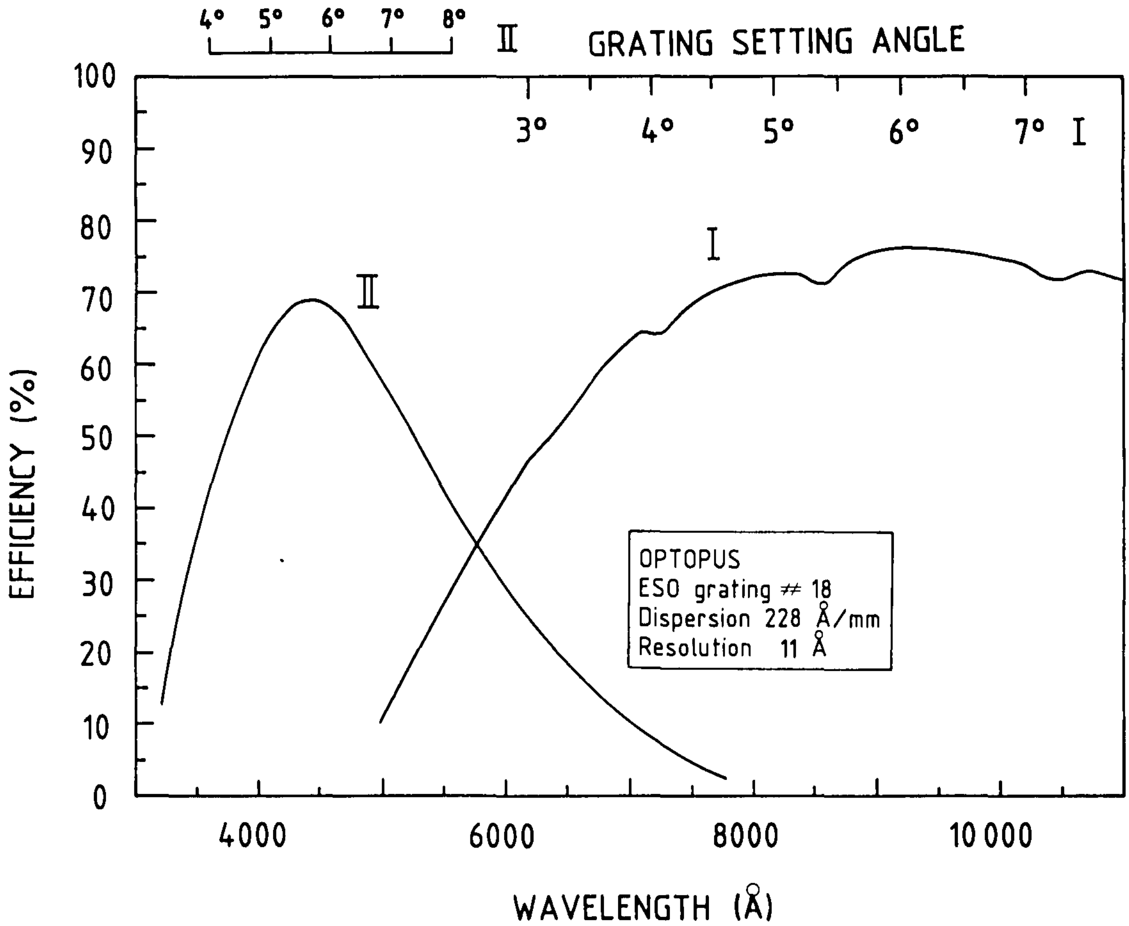

GRATING SETTING ANGLE
-1°
-0,5°
0°
0,5°
1°
1,5°
2°
I
I
OPTOPUS
ESO grating ≠ 13
Dispersion 450 Å/mm
Resolution 22 Å
EFFICIENCY (%)
100
90
80
70
60
50
40
30
20
10
0
4000
6000
8000
10000
WAVELENGTH (Å)

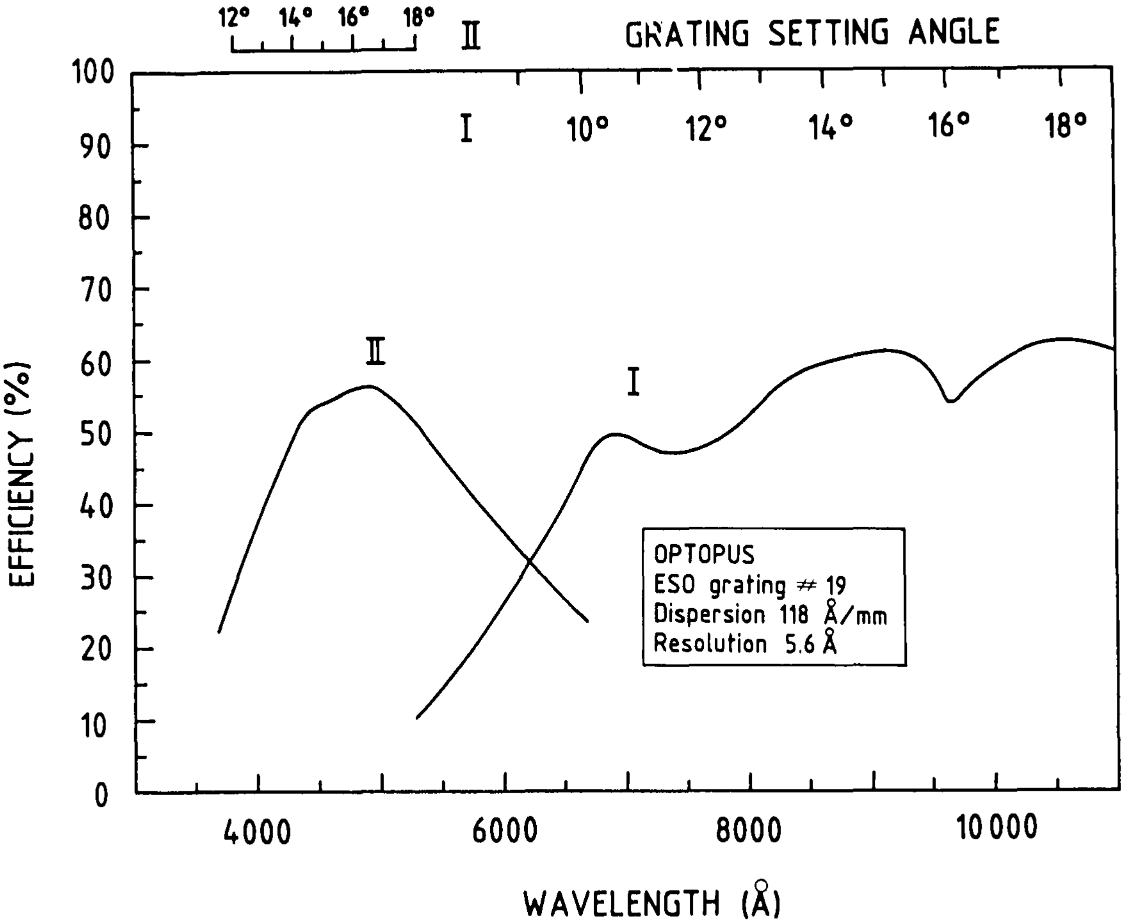

II
9° 10° 11° 12° 13° 14°
GRATING SETTING ANGLE
I
7°
8°
9°
10°
11°
II
I
OPTOPUS
ESO grating ≠ 14
Dispersion 172 Å/mm
Resolution 8.5 Å
EFFICIENCY (%)
100
90
80
70
60
50
40
30
20
10
0
4000
6000
8000
10000
WAVELENGTH (Å)

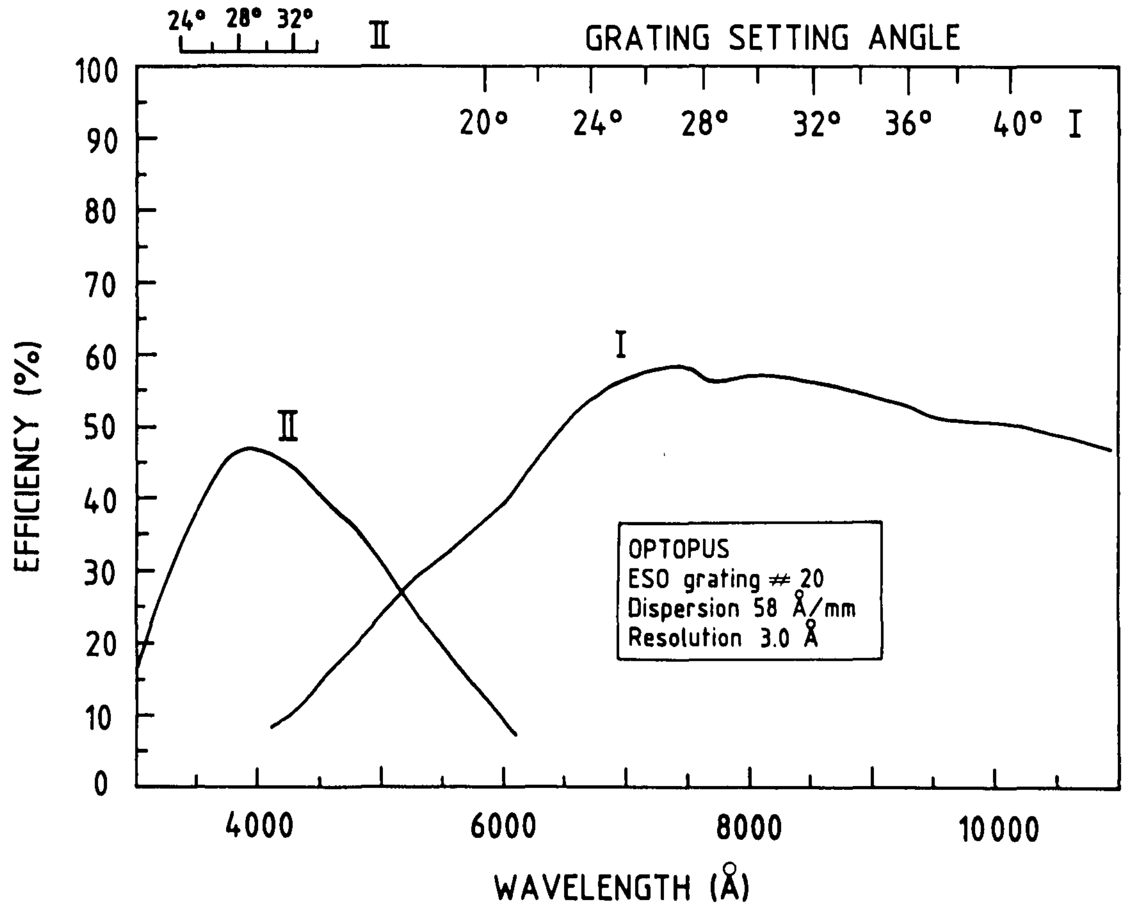

GRATING SETTING ANGLE
0° 1° 2° 3° 4° 5° 6° 7°
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
4000 6000 8000 10000
WAVELENGTH (Å)
OPTOPUS
ESO grating ≠ 15
Dispersion 224 Å/mm
Resolution 11 Å

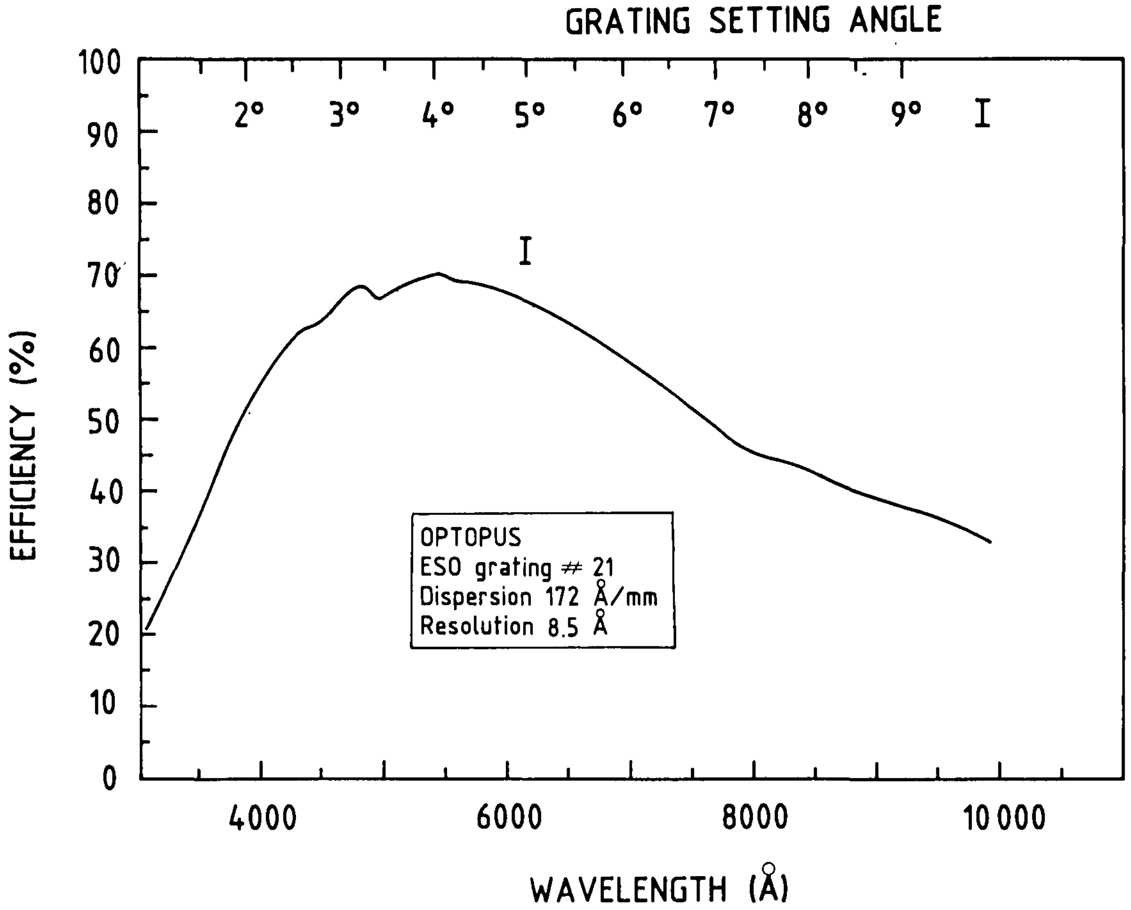

GRATING SETTING ANGLE
3° 4° 5° 6° 7° 8° 9° 10°
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
4000 6000 8000 10000
WAVELENGTH (Å)
OPTOPUS
ESO grating ≠ 16
Dispersion 172 Å/mm
Resolution 8.5 Å

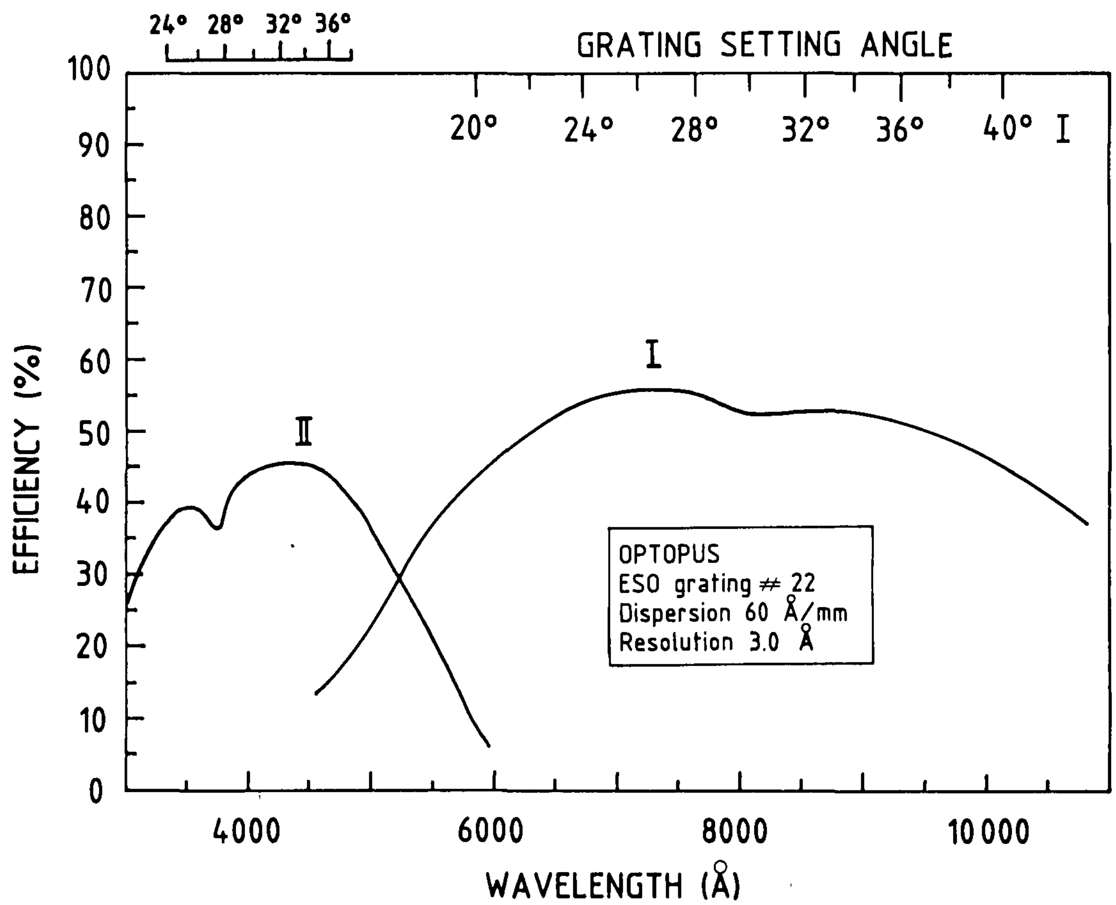

6° 7° 8° 9° II
GRATING SETTING ANGLE
I 3° 4° 5° 6° 7° 8° 9° 10°
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
I
II
OPTOPUS
ESO grating ≠ 17
Dispersion 173 Å/mm
Resolution 8.5 Å
4000 6000 8000 10 000
WAVELENGTH (Å)

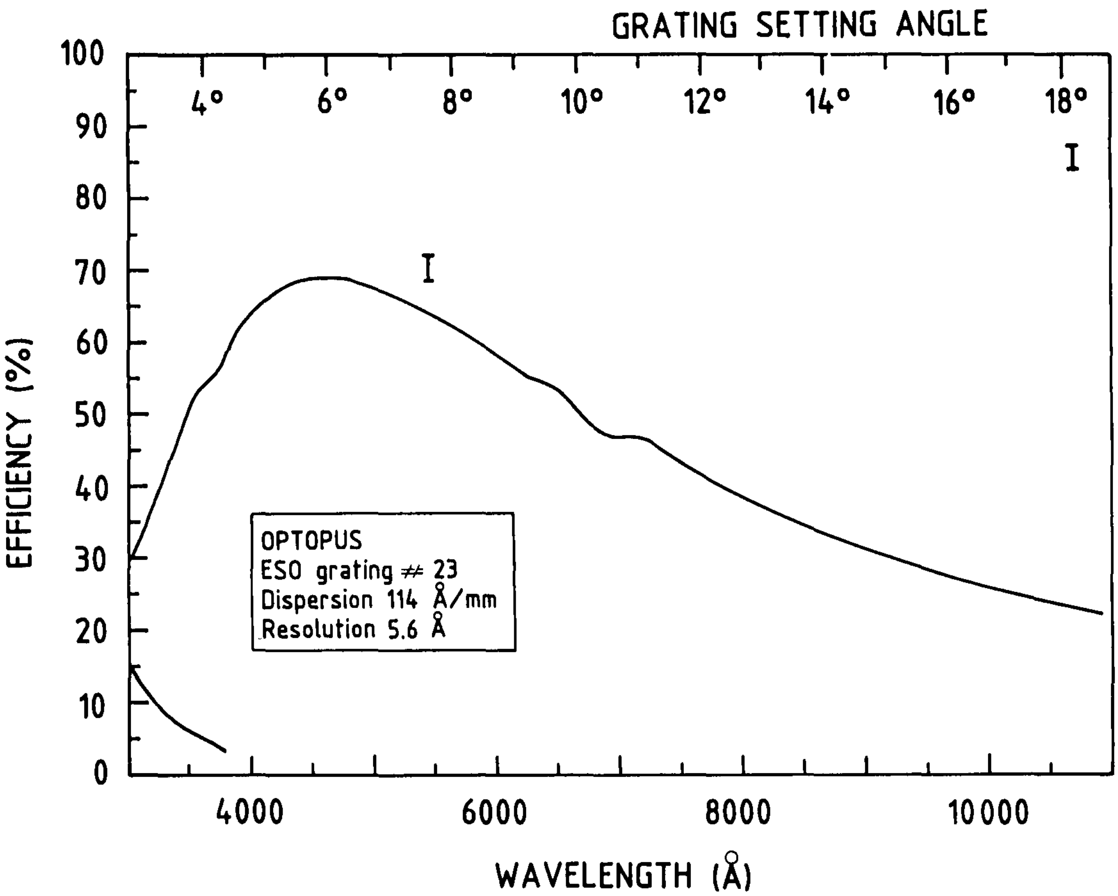

4° 5° 6° 7° 8° II
GRATING SETTING ANGLE
3° 4° 5° 6° 7° I
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
I
II
OPTOPUS
ESO grating ≠ 18
Dispersion 228 Å/mm
Resolution 11 Å
4000 6000 8000 10 000
WAVELENGTH (Å)

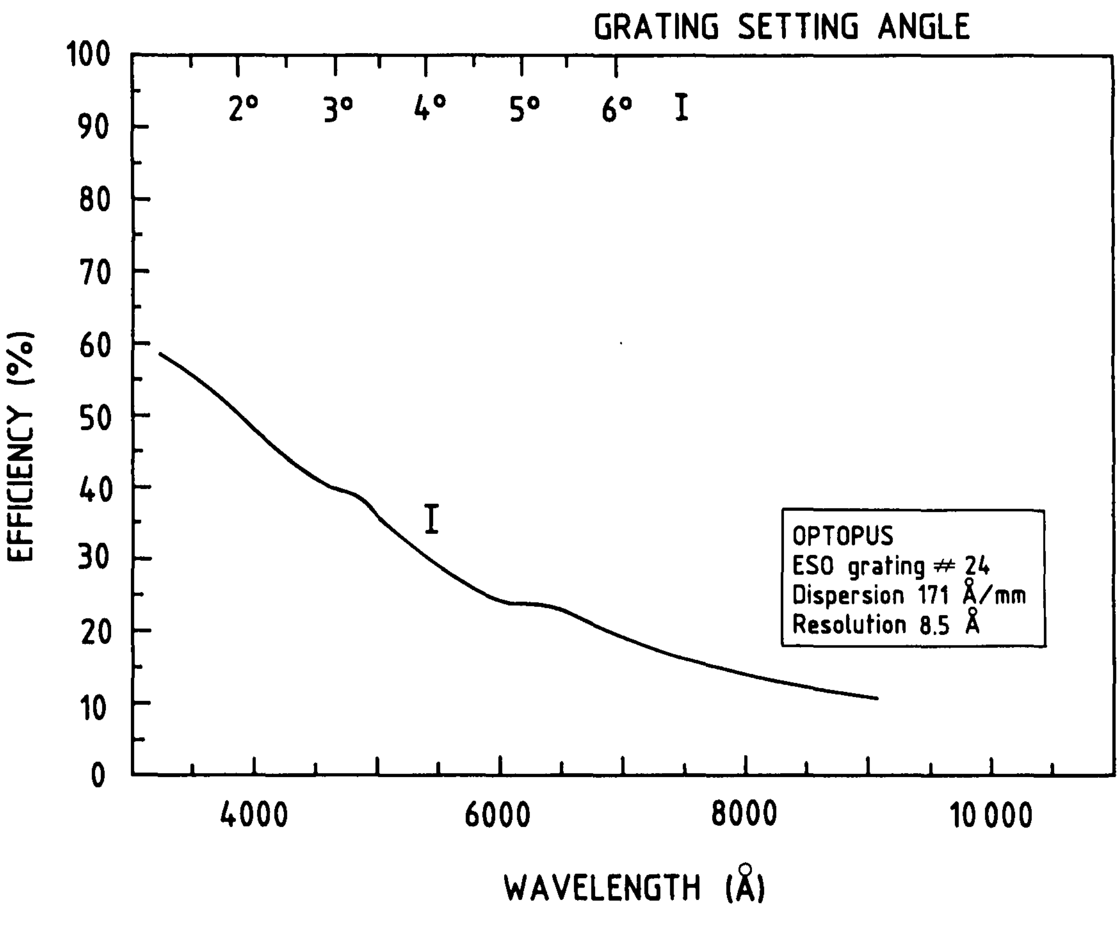

12° 14° 16° 18° II
GRATING SETTING ANGLE
I 10° 12° 14° 16° 18°
II
I
OPTOPUS
ESO grating ≠ 19
Dispersion 118 Å/mm
Resolution 5.6 Å
EFFICIENCY (%)
WAVELENGTH (Å)
0
10
20
30
40
50
60
70
80
90
100
4000
6000
8000
10000

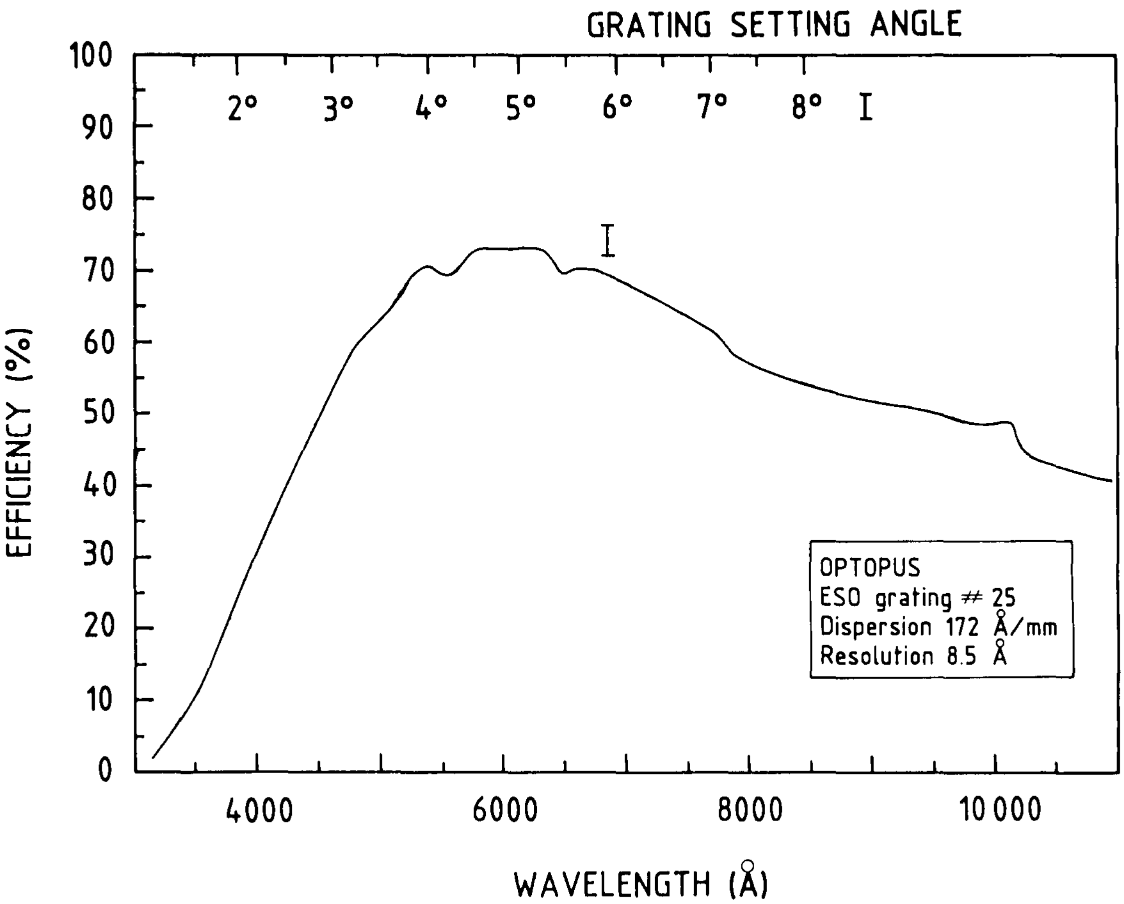

24° 28° 32° II
GRATING SETTING ANGLE
20° 24° 28° 32° 36° 40° I
I
II
OPTOPUS
ESO grating ≠ 20
Dispersion 58 Å/mm
Resolution 3.0 Å
EFFICIENCY (%)
WAVELENGTH (Å)
0
10
20
30
40
50
60
70
80
90
100
4000
6000
8000
10000

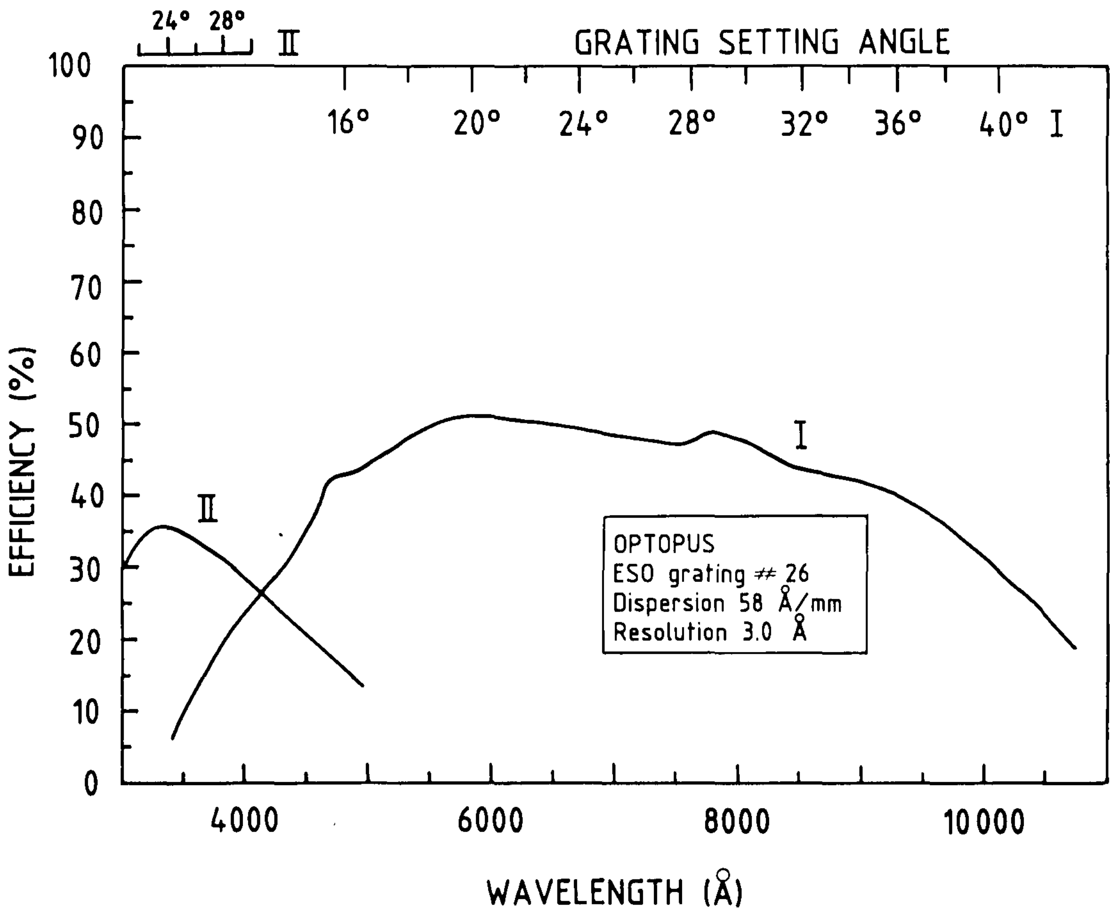

GRATING SETTING ANGLE
2° 3° 4° 5° 6° 7° 8° 9° I
I
EFFICIENCY (%)
0
10
20
30
40
50
60
70
80
90
100
OPTOPUS
ESO grating # 21
Dispersion 172 Å/mm
Resolution 8.5 Å
4000
6000
8000
10 000
WAVELENGTH (Å)

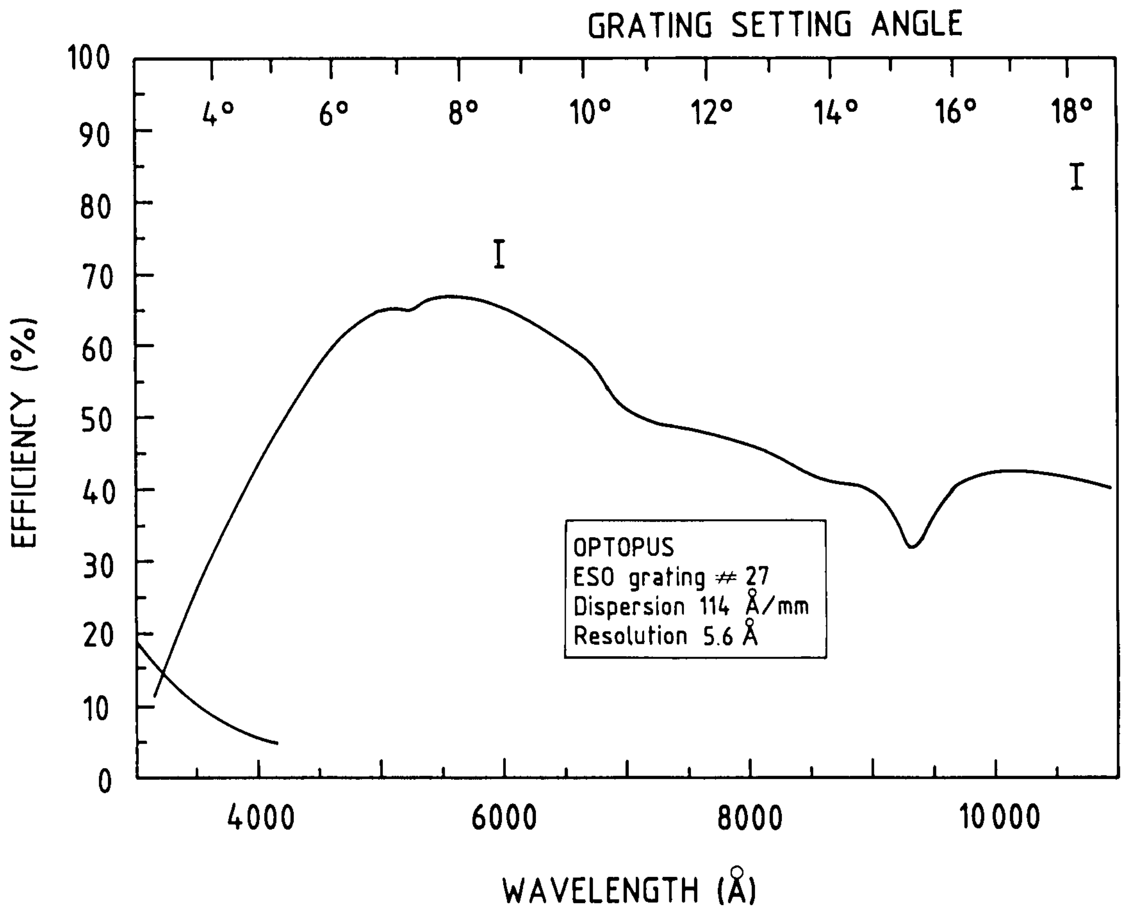

24° 28° 32° 36°
GRATING SETTING ANGLE
20° 24° 28° 32° 36° 40° I
I
II
EFFICIENCY (%)
0
10
20
30
40
50
60
70
80
90
100
OPTOPUS
ESO grating # 22
Dispersion 60 Å/mm
Resolution 3.0 Å
4000
6000
8000
10 000
WAVELENGTH (Å)

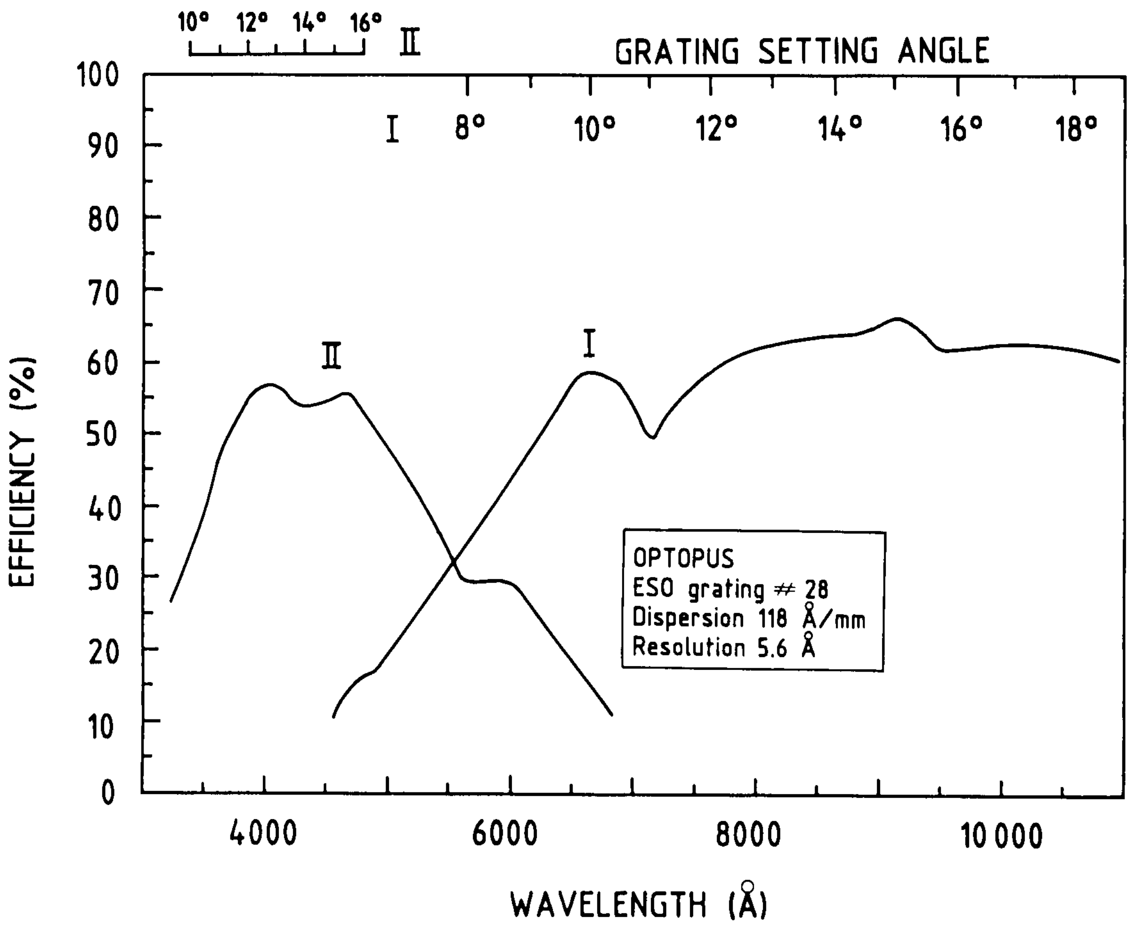

GRATING SETTING ANGLE
4° 6° 8° 10° 12° 14° 16° 18°
EFFICIENCY (%)
WAVELENGTH (Å)
OPTOPUS
ESO grating ≠ 23
Dispersion 114 Å/mm
Resolution 5.6 Å


GRATING SETTING ANGLE
2° 3° 4° 5° 6°
EFFICIENCY (%)
WAVELENGTH (Å)
OPTOPUS
ESO grating ≠ 24
Dispersion 171 Å/mm
Resolution 8.5 Å


GRATING SETTING ANGLE
2° 3° 4° 5° 6° 7° 8° I
I
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
4000 6000 8000 10 000
WAVELENGTH (Å)
OPTOPUS
ESO grating # 25
Dispersion 172 Å/mm
Resolution 8.5 Å


24° 28° II
GRATING SETTING ANGLE
16° 20° 24° 28° 32° 36° 40° I
I
II
EFFICIENCY (%)
0 10 20 30 40 50 60 70 80 90 100
4000 6000 8000 10 000
WAVELENGTH (Å)
OPTOPUS
ESO grating # 26
Dispersion 58 Å/mm
Resolution 3.0 Å


GRATING SETTING ANGLE
4° 6° 8° 10° 12° 14° 16° 18°
I
I
EFFICIENCY (%)
100 90 80 70 60 50 40 30 20 10 0
4000 6000 8000 10 000
WAVELENGTH (Å)
OPTOPUS
ESO grating # 27
Dispersion 114 Å/mm
Resolution 5.6 Å


10° 12° 14° 16° II
GRATING SETTING ANGLE
I 8° 10° 12° 14° 16° 18°
II
I
EFFICIENCY (%)
100 90 80 70 60 50 40 30 20 10 0
4000 6000 8000 10 000
WAVELENGTH (Å)
OPTOPUS
ESO grating # 28
Dispersion 118 Å/mm
Resolution 5.6 Å