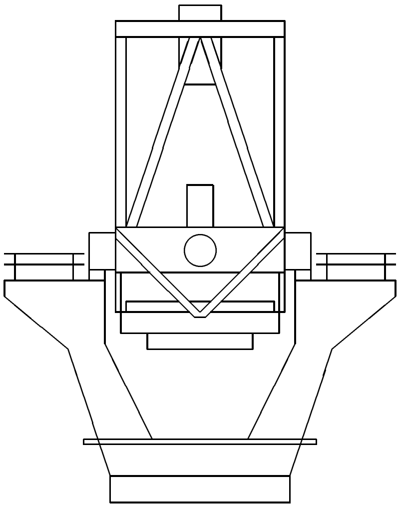
Roque de los Muchachos Observatory

Isaac Newton Group of Telescopes

AUTOFIB2/WYFFOS User Manual



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Contents

Chapter 1

Introduction

This manual describes the AF2 and WYFFOS instruments as a guide for visiting astronomers. Additionally some setup procedures of these instruments are put in as appendices, in order to aid support astronomers to prepare the instruments for observing. Information on field configuration and post-observation data analysis can also be found in the appendix.

For the latest version of this manual check the ING WWW pages.

1.1 AF2/WYFFOS

AUTOFIB2 is the WHT prime focus robotic fibre positioner. It was originally built within a collaboration between Durham and RGO. After commissioning the instrument was plagued by unreliability and consequently the robot and fibre module were re-engineered by ING staff.

When mounted on the telescope AUTOFIB2 is positioned behind the prime focus corrector. The fibres are positioned on a field plate by a robotic set of jaws with 3-d motion capability. The fibres are then run along the spider and then down the side of the telescope finally entering the GHRIL cabin feeding the bench mounted spectrograph WYFFOS built by RGO. The optical design of WYFFOS is optimized for fibre work having very little spatial magnification (hence many fibres can be installed on the pseudo slit and imaged onto the detector).

AF2 will eventually be offered with the choice of two fiber modules: the current Large-Fiber Module, with 2.7arcsec diameter fibers, and the Small-Fiber Module, with 2.7arcsec diameter fibers. The Small-Fiber Module will be on offer from the year 2000 onwards. For both modules the fiber positioning is subject to limitations: there is a minimum fibre spacing of about 30 arcsec, and the radially moving rods that hold the fibers are not allowed to cross. See Figure 1.1 for a typical AF2 setup.

WYFFOS is the RGO Wide Field Fibre Optic Spectrograph. In the first instance, the fibre feed is from the Prime Focus of the WHT, where the fibres are positioned automatically using AF2.

WYFFOS can be operated in reflection and transmission modes. However, as transmission mode has not proved to be useful, this mode is not offered for actual observations. In reflection mode the ISIS and IDS gratings can be mounted, as well as a dedicated WYFFOS echelle grating.

Table 1.1: Main parameters for the current AUTOFIB2 plus WYFFOS system

Prime Focus	
Field diameter	1 degree
Unvignetted field	40 arcmin
Plate scale	17.6 arcsec mm^{-1} (57.0 μm $arcsec^{-1}$)
Focal ratio	f/2.81
AUTOFIB*2*	
Fiducial fibres	ten 7–fibre guide bundles, res. 1 arcsec
Autoguider image probes	1 fixed, 1 moveable
Science fibres (Large)	126x153 μm diameter (2.7 arcsec)
Cycle Time	$\sim$16 sec per fibre
Positioning accuracy	better than 10 μm (absolute)
Science fibres length	26 m
WYFFOS	
Design	Baranne white pupil type
Slit optics (Large)	Sapphire microlenses
Collimator	f/8.2; $f = 820$ mm
Short Camera	f/1.2; $f = 132$ mm
Dispersion: Reflection mode	11.5–0.8Å $pixel^{-1}$
Resolving Power: Echelle mode	$\sim$8000
Detector	Thinned Tektronix TK1024: TEK6
Pixel size	24 μm

Currently WYFFOS is equiped with the Short Camera, a Schmidt design camera with TEK6 as fixed detector. As the TEK CCD has only 1024x1024 pixels it can accommodate about 150 spectra. In the future the Long Camera will be built, which is designed to be used with large CCD chips and offers twice the resolution of the Short Camera. With the Long Camera it should be possible to get the spectra of about 600 objects on the chip.

The main parameters for the WHT + AUTOFIB2 + WYFFOS system are given in Table 1.1.

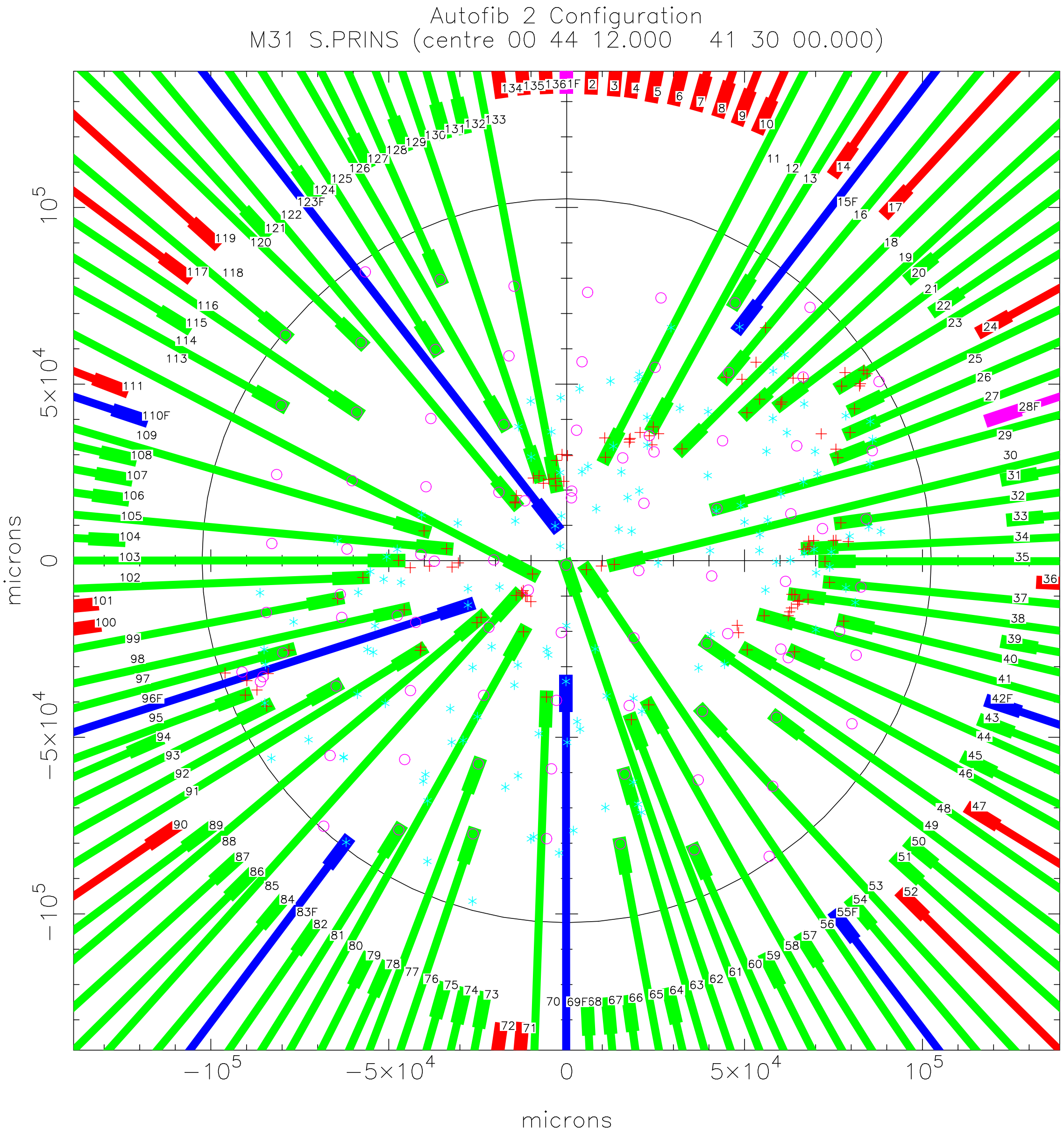


Figure 1.1: AF2 setup example (output of the af2-configure program). The dark coloured fiber rods hold fiducial bundles; plusses denote objects, star symbols denote fiducial stars, and open circles denote background or sky positions.

Chapter 2

AUTOFIB2

2.1 Prime Focus Corrector

The corrector was commissioned on the telescope in 1993, and gives on axis images better than 0.3 arcsec in diameter over the whole sky. Full-field photographic plates were obtained with the corrector in April 1994, and used to determine distortion coefficients (the corrected field suffers pincushion distortion). Results are that the coefficients are very close to those predicted by ray-tracing, and are stable with elevation (and hence Atmospheric Dispersion Compansation – ADC – angle). Direct comparison of two plates of the same field taken at elevations 30 degrees apart show residues at the level of 0.2 arcsec.

The ADC corrects for dispersion only. Atmospheric refraction still needs to be corrected for when setting up a field with AF2 (see section 6.2.3).

2.2 The Fibre Positioner

The fibre positioner is composed of a robot equiped with metalic jaws positioned on an xy table. The jaws themselves are capable of z and θ motion as is necessary for fibre placement.

Coupled to the robot is a TV camera that is alligned with the gripper. This camera can view the back-illuminated fibres and is used for fiber positioning and centroiding.

The robot also caries a probe to view the sky. This probe is called the mobile probe and is one of the two probes that feed light onto the autoguider CCD. The mobile probe is essential for field acquisition and for the acquisition of standard stars. The field of view of this probe is about 15x15 arcsec.

2.2.1 Performance

After re-engineering of the fibre module and gripper unit and an examination and characterisation of the electronics driving the gripper x, y, z, θ axes, the system was set to deliver a full

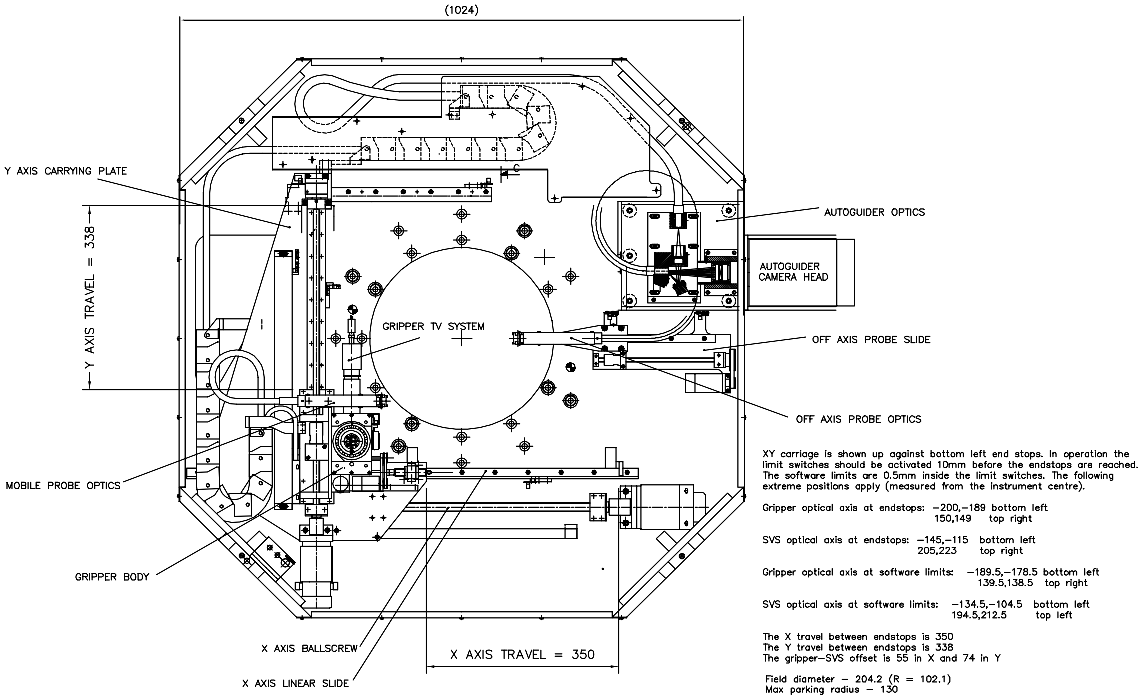


Figure 2.1: AF2 plan. The mobile and fixed (i.e. off-axis) probes look at the sky, and the gripper TV views the back-illuminated fibers.

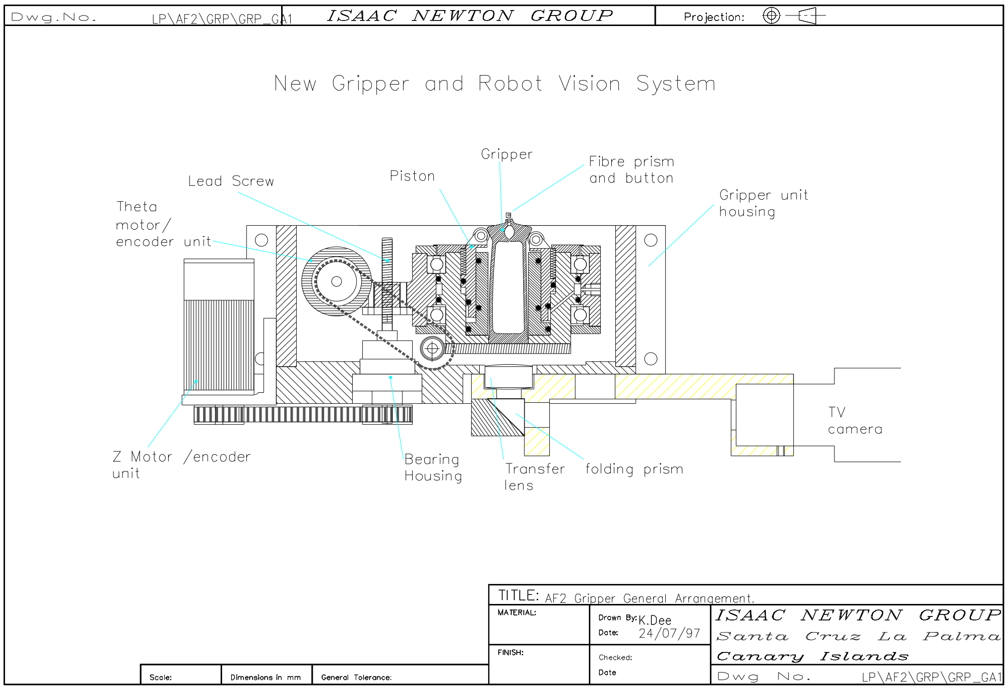


Figure 2.2: Gripper x-section after re-engineering by La Palma staff.

setup in about 30 minutes (or about 16 seconds per fibre). ING staff believe this figure can be easily reduced by a factor of 2 in the near future.

Due to an iterative placement process the absolute fiber positioning accuracy is better than 10μm RMS, i.e. better than 0.18 arcsec RMS. This accuracy can be reached as the system learns the typical positioning error of each fiber during succesive field setups, such that the gripper can account for the placement offsets of the fibers. After a fiber has been positioned, its location is measured by centroiding the back-illuminated fiber on the gripper TV, and this location is subsequently stored so that the system can easily find the fiber back.

2.3 The fibre feeds and fibre modules

On delivery AUTOFIB2 was supplied with a fibre module containing 126 science fibres each with a diameter of 2.7 arcsec: the Large-Fiber Module. The fibres were cut and optically coupled at the top ring during installation of the instrument. Tests during manufacture suggested that no more than ~10% light losses would be expected, but the practical gains in not having continuous fibres were considerable. Figure 2.3 shows the measured absolute efficiency of the fibre runs.

The science fibres and fiducial bundles are terminated at their input ends with SF5 microprisms whose input faces are wide-band coated. Their 92-degree angle provides median compensation for non-telecentricity, which amount to four degrees at the edge of the field. The residual maximum tilt of two degrees is still enough to produce a field dependant focal-ratio degradation (FRD) of focal ratio from f/2.8 to f/2.3 in addition to the intrinsic FRD of the fibre. This is one reason why an FRD-insensitive design was chosen for WYFFOS .

Each fibre is equipped with a magnetic button which holds it onto the field plate (which is flat to within 20 microns). The circular plate and its entourage of radially-disposed fibres are supported in a box from which the fibre cables trail to the spectrograph; the complete assembly constitutes a *fibre module*, which is easily removed from the robot to be interchanged with another. Coded proximity switches indicate to the AUTOFIB2 control system which fibre module is in place.

The Large Fibre Module is composed of 126 26.5 m lengths of high OH silica glass fibers, each with a diameter of 153 μm (subtending 2.7 arcsec on the sky). On the top ring of the telescope fibers coming from WYFFOS are coupled to the fibers coming from AF2. In order to position these fibers with the robot, they can be back-illuminated from within WYFFOS .

Semi-coherent bundles (composed of 7 indivual fibres, each bundle about 2 arcsec in diameter) give a crude imaging capability and are used for telescope focusing, alignment of fiducial stars, and manual guiding. These fiber bundles run from AF2 to the acquisition TV which is located at the top ring of the telescope, next to the science-fiber couplers. In order to position these fibers with the robot, they can be back-illuminated from within the box of the acquisition TV.

This fibre module has been in service now for a number of years and a number of fibres have been disabled because either they have been damaged in a collision or their transmission is so low that they cause problems during placement (these fibres are also of limited astronomical use). Figure 2.4 shows the relative transmission of the science fibers as derived in August 1998.

As the instrument has been in use for several years it is possible to compare fibre transmissions over this timescale (Figure 2.5). If there was no change in fibre transmission in this period only

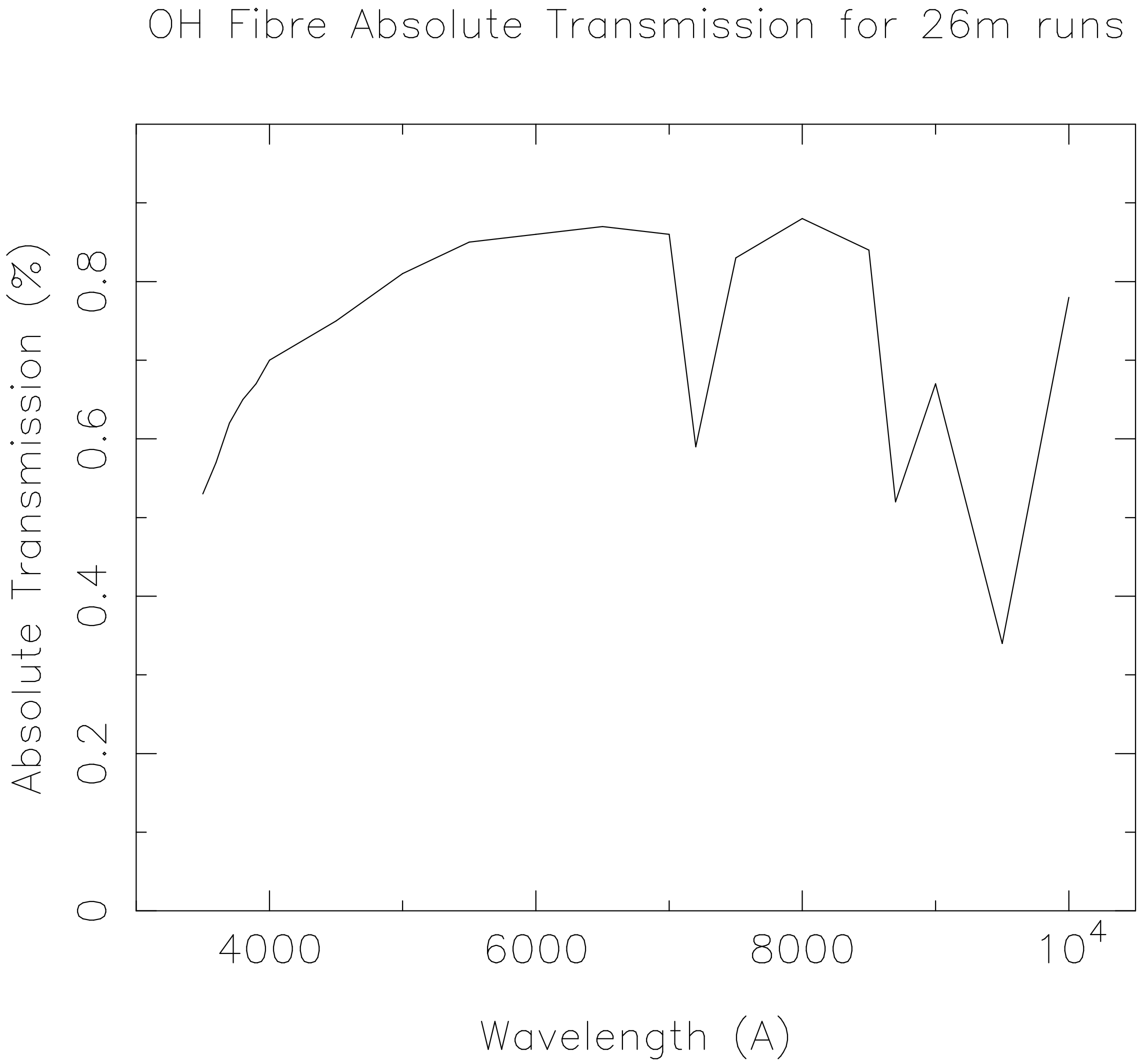


Figure 2.3: The absolute fibre transmission for the 150 μm fibre, 26 m WYFFOS fibre runs

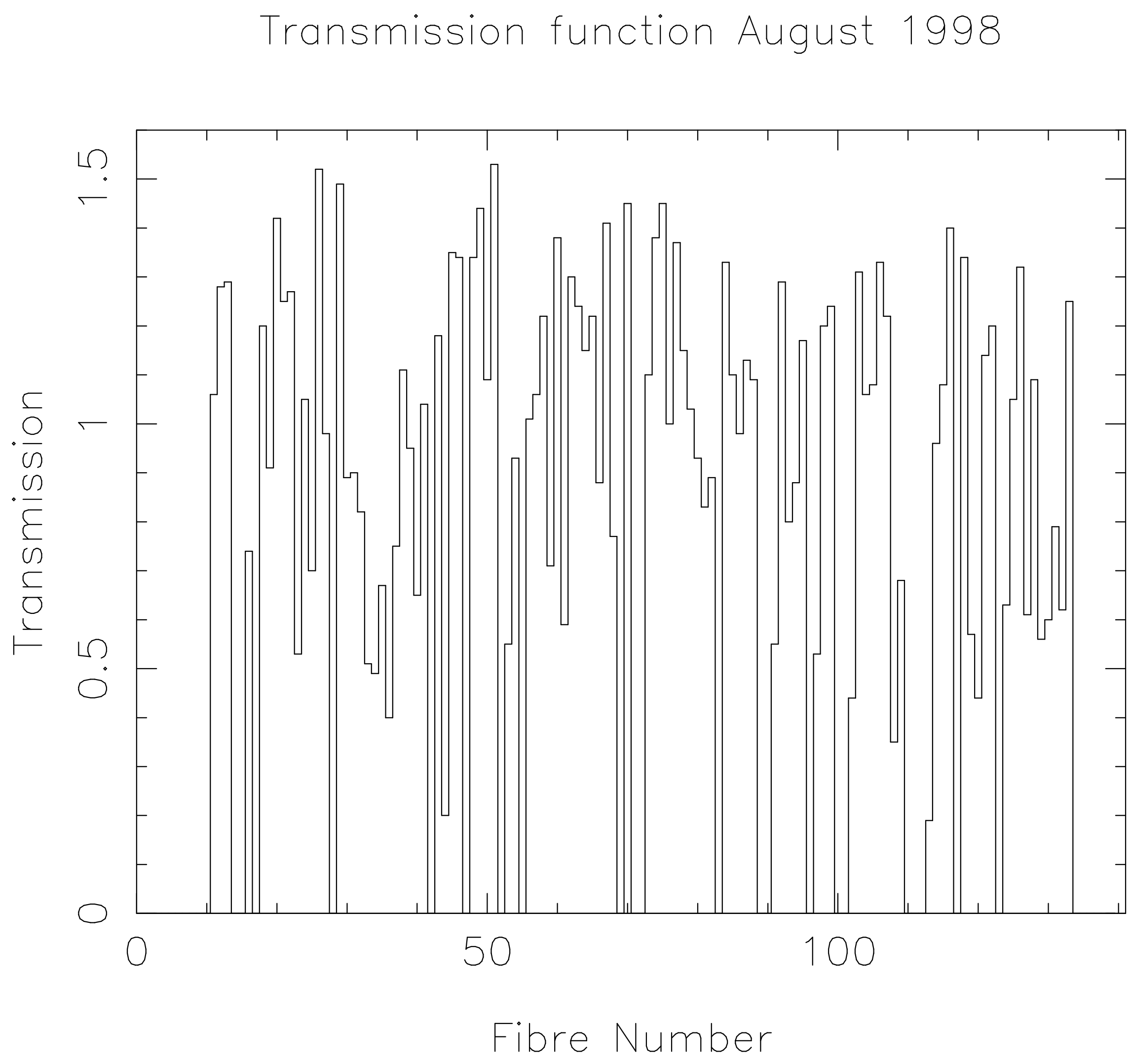


Figure 2.4: Fibre transmission function derived during the August 1998 AUTOFIB2 run. The transmission is shown relative to the average fibre transmission.

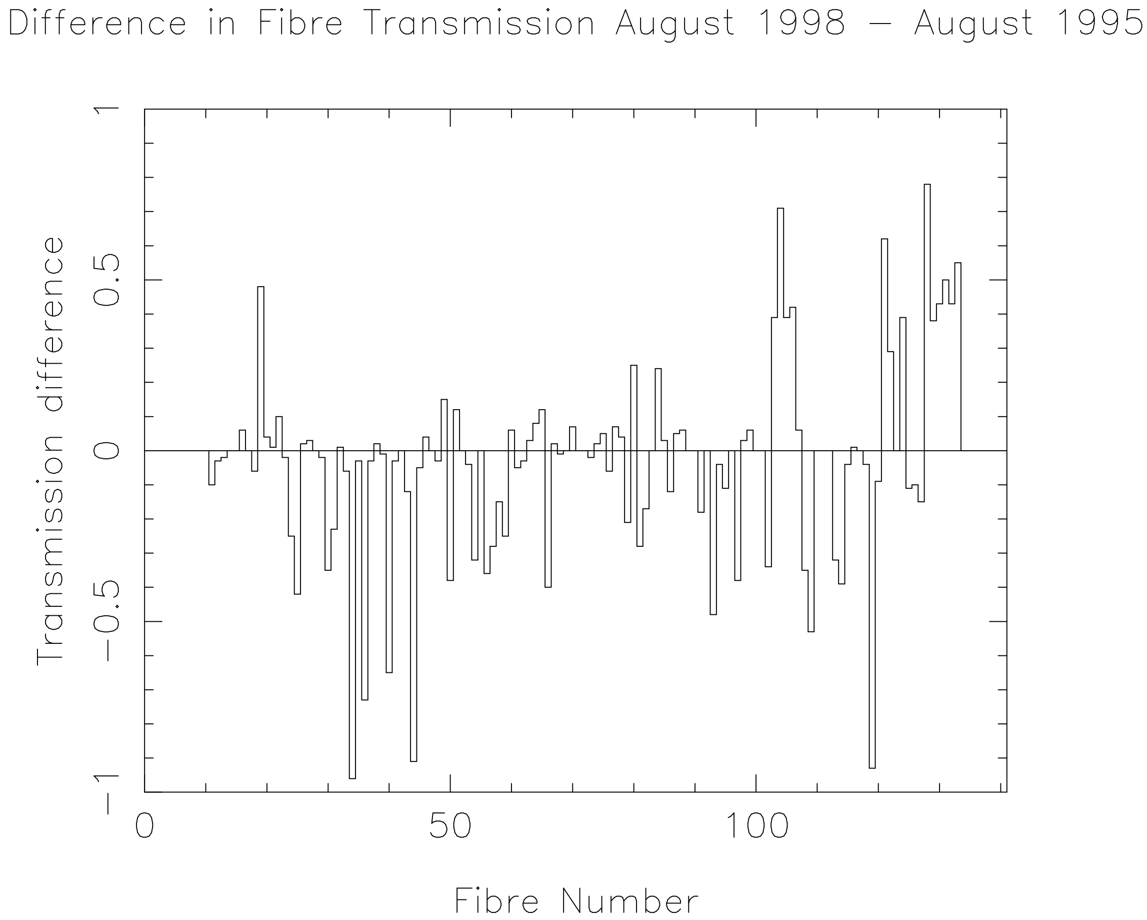


Figure 2.5: Variation in the fibre transmission measured over a three year period (August 1995 – August 1998). In the intervenuing period some nine fibres were disabled due to damage or low transmission. As these fibres would distort the above plot they have essentially been removed. The values for transmission variation are a true reflection of variations within the system.

small variations would be expected. However, it is evident that a large number of fibres exhibit large variations (disabled fibres have been excluded from this plot). The fact that a number of fibres appear to have increased transmission suggests that the optical couplers at the top ring are the culprits and produce unreliable results. This behavour is evident in transmission functions obtained at all other epochs. This figure does not rule out any long term degradation in fibre transmission at the 5–10% level.

A second fibre module is currently under construction by ING staff. Composed of 1.6 arcsec diameter fibre (the Small-Fibre Module) they will be continuous from the field plate to the WYFFOS slit unit. A further refinement of this module is the use of coherent fiducial bundles (probable covering 5x5 arcsec with 0.5 arcsec fibres).

2.4 Autoguider and sky viewing probes

AF2 has two sky viewing probes that feed their light onto the autoguider CCD. This autoguider CCD is fixed to the side of AF2 (see Figure 2.1), and can read out the signal from both probes simultaneously.

The mobile probe is fixed to the gripper robot and can be used for target acquisition. Its field of view is about 15x15arcsec.

The fixed probe (or off-axis probe), with a field of view of about ??x??arcsec, was originally intended for automated guiding. As the fixed probe obscures part of the field of view, hampers fibers to be placed on the field plate, and as it is difficult to find guide stars on the fixed probe, the fixed probe is practically never used for guiding. Manual guiding on the acquisition TV with the fiducial bundles is done instead.

Chapter 3

The WYFFOS spectrograph

3.1 Overview

WYFFOS is built on a dedicated optical table in the GHRIL cabin on one of the WHT Nasmyth platforms. It follows the white-pupil design of Baranne, in which a dioptric collimator is used in double-pass (near-Littrow) mode with a reflection grating to form an intermediate spectrum close to a concave spherical relay-mirror. The f/1.25 Schmidt-type camera works at finite conjugates to re-image the intermediate spectrum onto the detector, while the function of the relay mirror is to image the collimator pupil onto the camera pupil. The configuration offers considerable stability with respect to vignetting, and allows modification of the effective pupil to ease the camera design and reduce the effect of the central obstruction. Figure 3.1 shows the layout of the optical path in WYFFOS .

The reflection grating can be replaced with an echelle for higher-dispersion work. Introducing a second collimator (with the relay mirror and camera re-positioned) permits the use of a grism for *supposedly* high-throughput, low-dispersion work.

WYFFOS is controlled using EPICS/VxWorks on a VME micro. Motor drives operate slit translation and focus, filter slides and the grating table, while the Hartmann shutters on the camera are operated pneumatically. The spectrograph shutter is under direct control of the CCD controller. The VME communicates with the observing system on the VAX, and thence with AUTOFIB2.

3.2 Slit section

The indivual fibres are arranged in groups of nine, set onto the *curved* slit of radius 1190mm, directed towards the centre of the first collimator in order to minimise vignetting at the collimator. In the slit matrix the AF2 fibers are staggered in groups of 3, which means that adjacent spectra are offset in the spectral direction. The AF2 fibers are not put in the slit matrix in a continuous order; see Table 3.4 for cross reference between WYFFOS apertures and AF2 fiber numbers. The slit section can be adjusted for for-aft (focus) and up-down (translation) motion, through software. Adjusting the translation would move the pattern in Figure 3.3 from left to right or reverse.

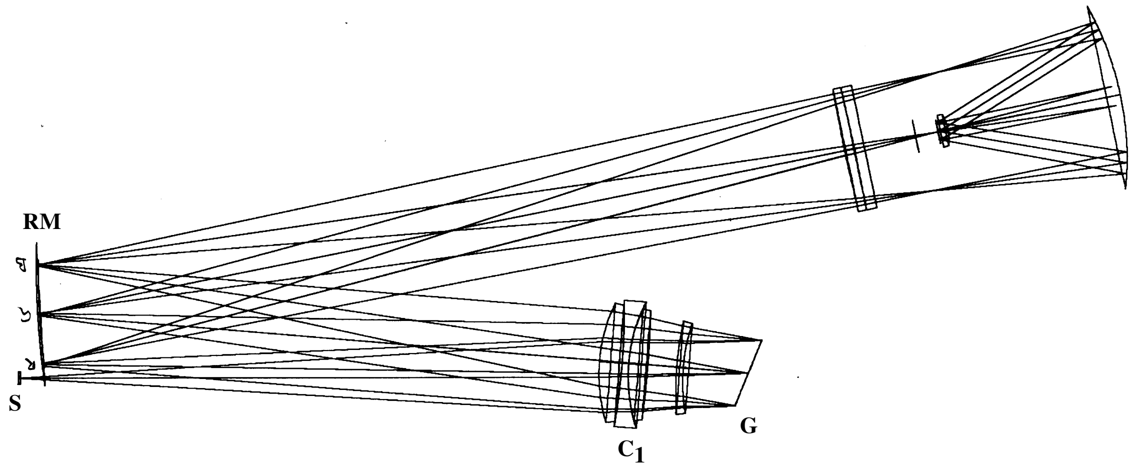


Figure 3.1: The optical path of WYFFOS in reflection/echelle mode: Slit, Collimator, Grating, Relay Mirror, and camera.

Different slit matrices can be loaded in WYFFOS for use with other instruments, such as INTEGRAL.

Light from the fibres emerges at f/2.5 (instead of f/2.8 due to focal-ratio degradation, FRD) and is then slowed to f/8.2 using microlenses, which form a real exit pupil at the focus of the collimator. Forming the real pupil means it is possible to introduce a real slit at this position to control the FRD.

The beam emerging from each fibre is matched to the f/8.2 collimator. Immediately beyond the fibre 'pseudo' slit is the spectrograph shutter, whose rear surface is used as a reflector for the fibre back-illumination source (an array of IR LEDs). Two filter slides follow, while the beam is still relatively narrow.

3.3 Filters

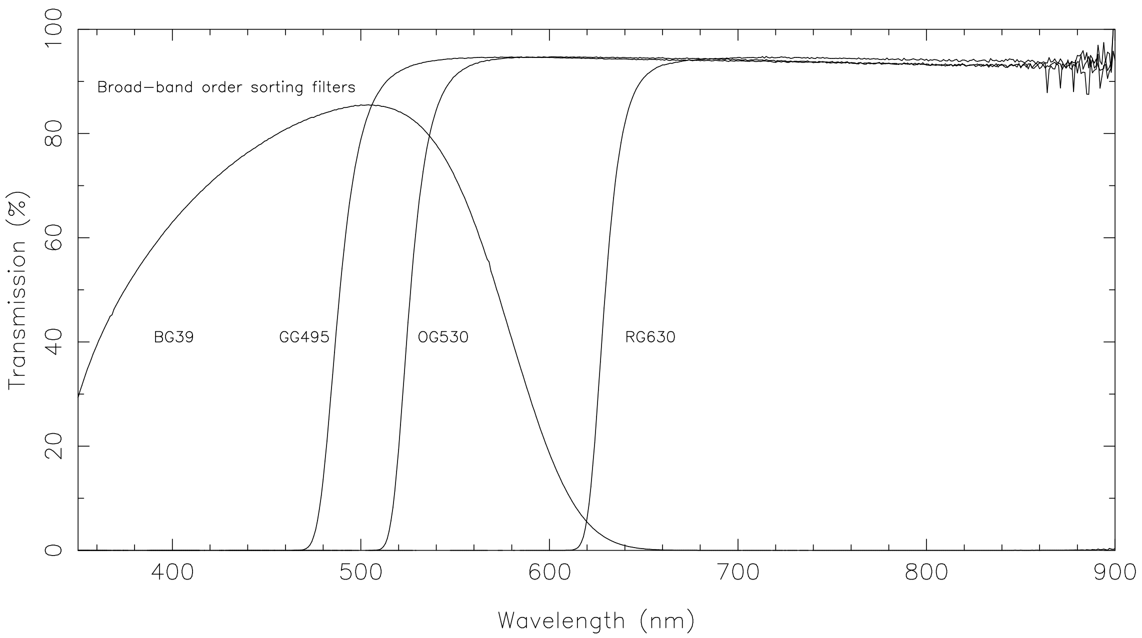
Due to the unusual physical dimensions of the WYFFOS slit, filters used in the spectrograph are expensive and difficult to obtain. Currently (1999), four broad-band order sorting filters are available for use in reflection mode (top graph of Figure 3.2), and a further five are available for order isolation in echelle mode. The echelle filters have interference coatings and have been selected to isolate important astrophysical diagnostics (e.g. Hα).

The corrections to the slit focus for the filter thicknesses are given in Table 3.1.

3.4 Collimators

Passing the two filter slides, the light falls onto the first collimator. In reflection (and echelle) mode only the first collimator is part of the light path. The four-element collimator is wide-band coated, though it's twin for use with the grism has a multi-layer coating (???).

Collimator: transmission is analogue to the Schmidt type collimator. The two biconvex elements in the triplet are ultran 20; the separate meniscus lens is an aspheric.



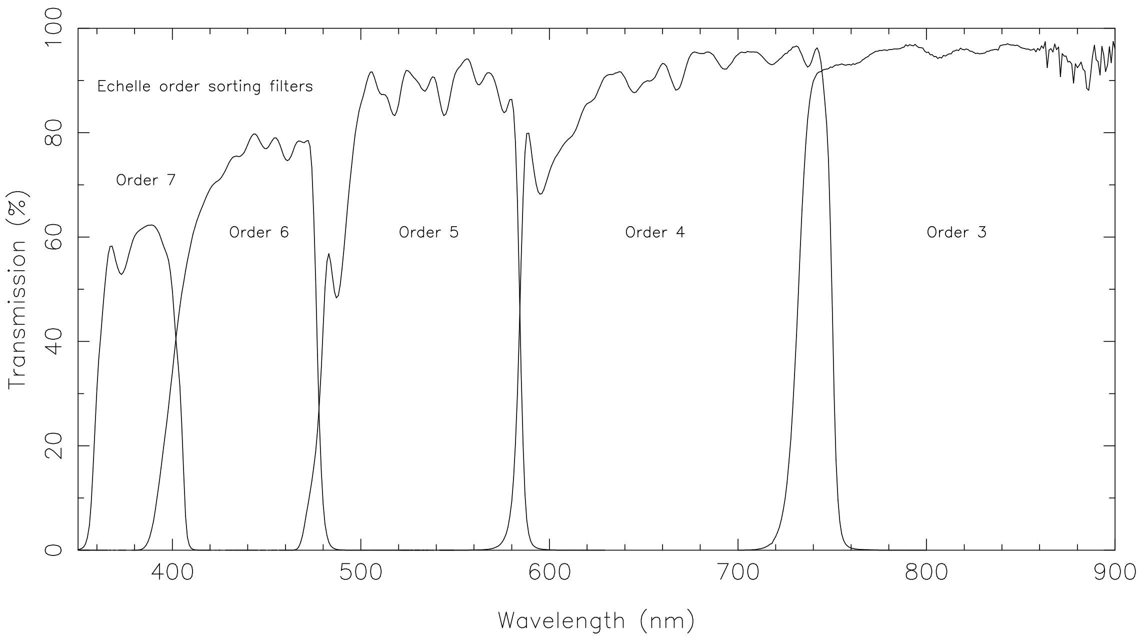


Figure 3.2: filter scans

Table 3.1: filter table

Filter identification	Thickness (mm)	Focus Offset (μm)
BG39	3.00	+1000
GG495	3.00	+1000
OG530	3.00	+1000
RG630	3.00	+1000
Echelle Filters		
8830Å (order 3)	6.00	+2000
6625Å (order 4)	6.10	+2003
5300Å (order 5)	4.12	+1373
4415Å (order 6)	6.10	+2003
3785Å (order 7)	5.90	+1997

3.5 Reflection Mode

The collimated beam then passes onto the grating, back through the collimator at a small angle (7.1 degree), relative to the incoming beam, towards the relay mirror. An image is formed close to this mirror, which then becomes the object for the re-imaging camera.

The WYFFOS grating cell is similar to that used in ISIS and consequently gratings from that instrument can be used directly in WYFFOS . Furthermore, using an adaptor, gratings from the IDS spectrograph can also be used; the most popular being the H1800V grating. Note however that the IDS gratings are smaller than the beam in WYFFOS , so these gratings vignette the fibers at the top and the bottom ends of the slit. Table 3.2 lists the gratings currently available along with dispersion and instrumental resolution with the available fibre modules.

Note, spectral resolution is determined by the projected fibre diameter rather than the instrumental resolution: for the 153 μm fibres of the Large-Fibre Module the projected diameter is 3.4 pixels.

3.6 High Order or Echelle Mode

Insertion of a 632 l/mm grating into the grating cell moved back by 68 mm allows high spectral orders to be accessed with a suitable order sorting filter – see Section 3.3 for information on the available filters and Table 3.3 for the dispersion in echelle mode. The Milton Roy echelle grating has a blaze angle of 57,° which corresponds to 2649 nm in first order, and to 2649 nm/2 and 2649 nm/3 (etc.) for second and third orders respectively.

3.7 Transmission Mode

The collimated beam passes through a grism where the beam is deviated by a small angle (4.4 degrees at 5860Å), through a second collimator onto a relay mirror, angle forming a real image

Table 3.2: Physical characteristics for the WYFFOS reflection gratings with the Large and Small-Fibre Modules. The H1800V grating is from the IDS and is used with a special adaptor.

Grating	Wavelength (Å)	Dispersion (Å/mm)	Large Fibres Instrumental resolution (Å)	Small Fibres Instrumental resolution (Å)	CCD resolution (Å/pixel)	Spectral range (Å)
R158B	3600	479	39.0	23.1	11.0	—
R158R	6500	479	39.0	23.1	11.0	—
R300B	4000	250	20.5	12.1	6.0	6150
R316R	6500	240	19.5	11.6	5.5	5630
R600B	3900	126	10.2	6.0	3.0	3080
R600R	7000	126	10.2	6.0	3.0	3080
R1200B	4000	63	5.1	3.0	1.5	1540
H1800V	5500	47	3.8	2.3	1.2	1160
R1200R	7200	63	5.1	3.0	1.5	1540
H2400B	4000	31.5	2.5	1.5	0.8	774

Table 3.3: Physical characteristics for the WYFFOS Echelle Mode with the Large-Fibre Module

Order	Wavelength Å at blaze	Grating efficiency (%)	Disp. Å/mm	Disp. Å/pix	Free Spectral Range (Å)	CCD coverage (Å)
3	8830	53	23.73	0.57	2940	580
4	6623	46	17.80	0.43	1650	435
5	5298	43	14.24	0.34	1060	350
6	4415	39	11.87	0.28	740	290
7	3784	?	10.17	0.24	540	245

close to this mirror. This image again becomes the object directed towards the (turned around) re-imaging camera.

The efficiency of the grism appeared to be very low (30% overall). As the system did not perform as well as expected with the grism, transmission mode will not be offered.

3.8 Short Camera

The Schmidt camera is fed from the relay mirror which images the collimator pupil onto the camera pupil. The camera re-images the spectral image that is formed close to the relay mirror. The TEK6 (1024x1024 24μm pixels) detector sits in the curved focal plane of the camera on a cold finger protruding from its cryostat.

Mirrors are overcoated silver, while the doublet Schmidt corrector and field-flattener of the camera are wide-band coated.

The cycle between AF2 fibres with the present camera is ~8.5 pixels for the large fibres. There is a clear gap of ~2 pixels between adjacent spectra. The FWHM of spectra of Tungsten lamp

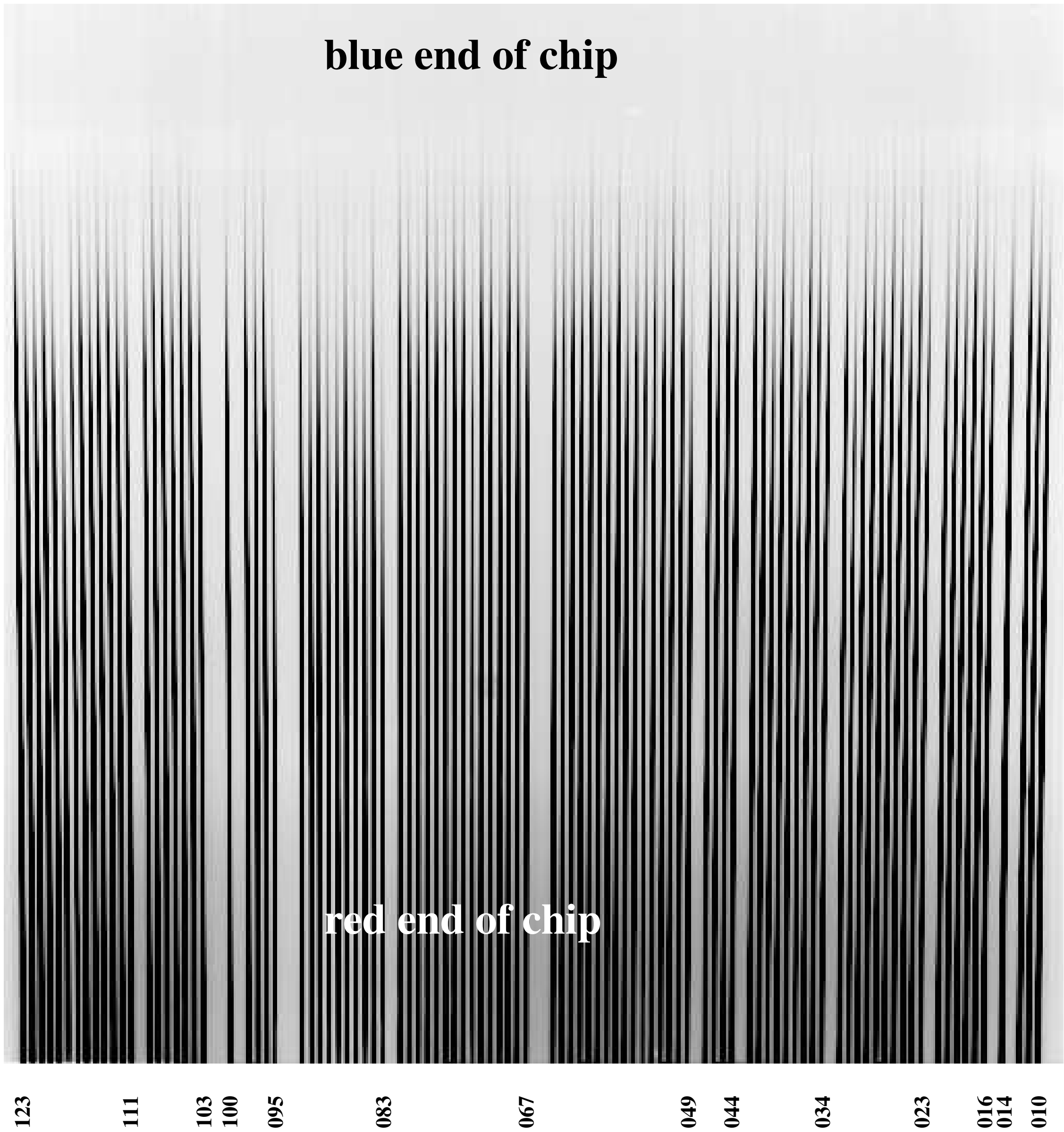


Figure 3.3: A CCD image of AF2 large fibers with WYFFOS in reflection mode, using the R316B grating. For this exposure all available AF2 science fibers were illuminated by the Tungsten lamp from the calibration unit at broken Cas, which hardly emits in the blue. At the bottom the aperture definition that is used for Table 3.4 is given: the fibers without a number have aperture numbers sequentially increasing from right to left.

Table 3.4: Cross reference between AF2 fibre numbers and the aperture numbers, see Figure 3.3 for identification of the apertures. The last two apertures of this table are not illuminated in Figure 3.3

Ape	Fib	Ape	Fib	Ape	Fib	Ape	Fib	Ape	Fib	Ape	Fib
10	11	34	37	56	61	78	85	104	103	22	24
11	12	35	38	57	62	79	88	105	104	66	72
12	13	36	39	58	63	80	79	106	105		
14	16	37	40	59	64	81	80	107	106		
16	18	38	41	60	65	83	89	108	107		
17	19	39	43	61	66	84	91	109	118		
18	20	40	44	62	67	85	92	111	120		
19	21	41	45	63	68	86	93	112	121		
20	22	42	46	64	70	87	94	113	122		
21	23	44	48	67	73	88	95	114	124		
23	25	45	49	68	74	89	97	115	125		
24	26	46	50	69	75	90	98	116	126		
25	27	47	51	70	76	91	108	117	127		
26	29	49	53	71	77	92	109	118	128		
27	30	50	54	72	78	95	113	119	129		
28	31	51	56	73	82	96	114	120	130		
29	32	52	57	74	84	97	115	121	131		
30	33	53	58	75	81	98	116	122	132		
31	34	54	59	76	86	100	99	123	133		
32	35	55	60	77	87	103	102				

exposures is about 2 pixels, but due to the curvature of the focal plane in the Schmidt camera the FWHM can be about 3 pixels in the corners of the chip. Figure 3.3 shows an image of the AF2 apertures on the chip. In addition to the 12 disabled science fibers which would be imaged beyond the chip edges, one can spot the gaps of 15 disabled fibers.

With the TEK CCD the short camera can accommodate about 150 fibers; a larger chip would vignette the field of view of the camera. The long camera will allow up to 600 fibers and twice the resolution of the short camera.

3.9 Ghosting and scattered light

As in any spectrograph WYFFOS suffers from ghosting. In this case, the small angle between the light path on its two passes through the collimator, which results in the low spatial magnification (required for a fibre spectrograph), allows scattered light to enter the camera.

The Baranne optical layout introduces contamination of the spectra due to reflection of undispersed white light from the collimating lens surfaces. This has been measured to be about 5% of the total flux, which should be reducable by using coloured filters.

For some setups additional and very noticable scattered light ends up at the red end (bottom) of the chip.

Chapter 4

The AF2/WYFFOS calibration unit

The calibration unit is mounted at the broken-Cassegrain focus and contains one slide with lamps and two filter slides. Operation of the unit is computer controlled, with the software running on the Solaris cluster. As the lamps are on a slide that moves into position, the Neon and Argon lamps can not be used together.

The system works by shining the light onto the tertiary mirror which is then relayed to the fibres at prime. Consequently, light from the arc lamps can be superimposed on the starlight, although usually separate arc frames will be obtained.

Comparison lamp slide positions:
1 Tungsten
2 Neon
3 Argon
4 Copper Argon

Filter slide A:
1 empty
2 ND 2.0
3 ND 3.0
4 ND 1.0
5 ND 0.5
6 Empty

Filter slide B:
1 empty
2 TG 395
3 BG 38
4 empty
5 empty
6 empty

Chapter 5

Throughput of AF2/WYFFOS

5.1 Sensitivity in Reflection Mode

Figure 5.1 shows recent measurements of the sensitivity of the Large Fiber system in reflection mode. Compared to other WHT instruments the figures are not impressive. One contributing factor to the photon loss is the difficulty in centring the flux standard in a particular fibre with no light losses (with ISIS a slit wider than 2.7 arcsec would be used). Other sources of efficiency loss include the optical couplers for this module, chip sensitivity and fibre transmission efficiency.

5.2 Sensitivity in Echelle Mode

In echelle mode the following sensitivities were derived from a commissioning run in August 1998 (Table 5.1). From a consideration of the grating, fibre and filter efficiency the values look reasonable when compared to those obtained in reflection mode with the ISIS gratings and without a filter in the light path.

Table 5.1: Sensitivity as measured with the TEK6 detector for WYFFOS in echelle mode.

Order	Wavelength (Å)	AB e/s/Å
3	8630	15.2
4	6625	16.4
5	5300	16.1
6	4415	15.0
7	3785	13.3

5.3 Sky Subtraction

Achieving the best possible sky subtraction with fibres requires careful planning and observing strategies, and inevitably involves tradeoffs. For instance, one can assign an 'sky' fibre next to

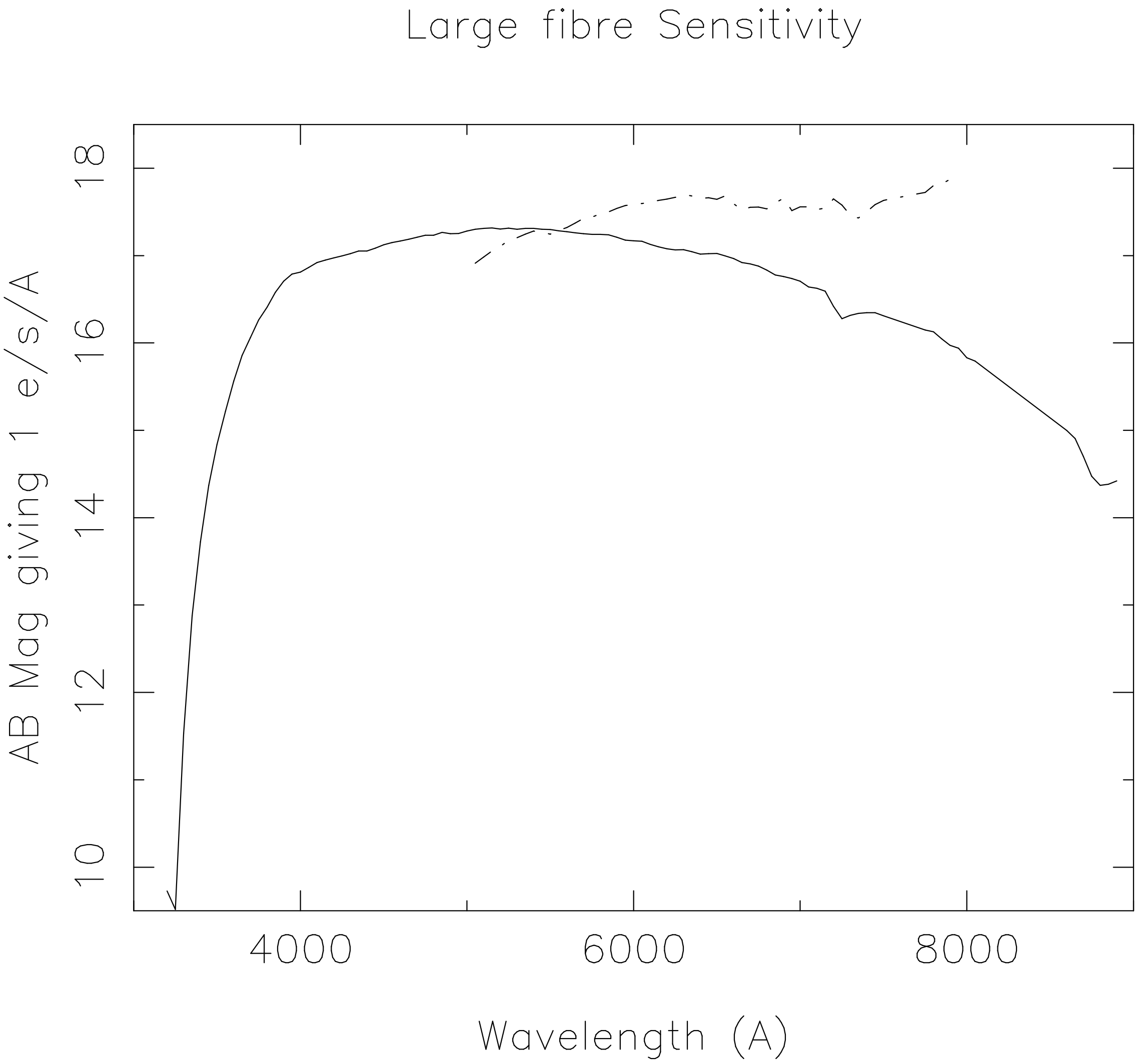


Figure 5.1: Sensitivity of WYFFOS in reflection mode, with TEK6, determined from the R300B and R600R (dashed line) gratings.

each object fibre, which reduces the fibre multiplexing advantage by a factor of 2. Another strategy is to 'beam-switch' the telescope back and forth between objects and the neighboring sky, but this of course reduces the integration time on source.

Sky subtraction with fibres is never as good as with a slit spectrograph, since one is limited by the fibre diameter. At present the best sky subtraction we have achieved with AF2/WYFFOS is 3% (based on the RMS residuals on dedicated sky fibres in a twilight sky frame), but that was for the system when it displayed large scattering caused by deposit on the field-flattening lens.

A limitation of AF2/WYFFOS is the large fibre diameter of 2.7arcsec. For point sources, because of the large sky contribution, the S/N is lower than for the fibers of the anticipated Small Fiber Module.

Chapter 6

An Observing Primer

6.1 Observation Preparation

6.1.1 Astrometry and fiducial star selection

The total error in positioning a fibre arising from inaccuracies in placement and that in the prime focus distortion field is < 0.4 arcsec, hence, astrometry should be, at the worse, of comparable accuracy. *Great care should be taken to ensure that fiducial stars are on the same astrometric reference frame as the program objects.* Reliable results have been obtained using APM and more recently with SUPER-COSMOS measurements. If deriving positions from CCD images great care must be taken in selecting secondary astrometric stars ensuring that these stars are not saturated.

As fibres cannot be crossed in the Large/Small-Fibre Modules a reasonable number of uniformly distributed fiducial stars should be obtained (say about 30). These stars should be selected to have $B \sim$ 14-15, with the bright limit imposed by the requirement that measurable proper motion is absent (and uncontaminated by diffraction spikes on photographic plates which produce inaccuracy in the astrometry). The faint limit comes simply from getting an image of the fiducial with short integrations for alignment and guiding purposes. Due to limitations in the dynamic range of the Westinghouse camera viewing system, fiducials should be selected to have comparable brightnesses.

6.1.2 Field configuration

After preparation of a catalogue of targets, a generous number of fiducials stars, and possibly sky positions, the AF2_CONFIGURE program should be used to optimize the fibre–object assignment. See E.1 for details on the use of this program. Before any configuration is attempted your support astronomer should be contacted in order to obtain the most up to date versions of the prime geometry description file (*whtprime.dat*) and current fibre description file (*large/small_fibres.dat*). Currently these files can be obtained from our AF2/WYFFOS WWW pages.

For proper field acquisition one needs at least 3 fiducial stars, but preferably more than 4. The buffer size that the AF2_CONFIGURE program asks for shuld be set to 1.5.

Before arriving at the telescope it is worth printing out the configuration files and plots of the fibre positions.

6.2 At the telescope

As with other instruments at the WHT the observing and data acquisition system is started from the MicroVAX lpvs1 and runs a remote session on the MicroVAXes lpvg or lpvf under the *observer* account. The system is slow to start up requiring some 15-20 minutes for a full restart.

6.2.1 FTP the .cfg files to the VAX

FTP your .cfg files to the [OBSERVER.AF2] directory on the VAX (lpvf or lpvg), using the OBSERVER VAX account.

6.2.2 Field setup and acquisition

Wake the gripper robot with
`ICL> AFWAKE .`
After ftp-ing the configuration file into the VAX directory `[OBSERVER.AF2]` on the system computer, moving fibres is straightforward using the observing software:
`ICL> AFSETUP field.cfg`
where `field.cfg` is the name of the configuration file placed in the `[OBSERVER.AF2]` directory. After reminding the user to turn down the gain for the Westinghouse TV system, the routine will request the sidereal time that the field was configured for and then turn the science-fibre back illumination on. The configuration file is then passed to the AUTOFIB2 micro where the fibre positions and movements are checked for illegal operations. Then the fibre back illumination is turned on and fibre repositioning commences.

In practice it is worth positioning the telescope and rotator on the field (or at least at roughly the same alt-az) to guard against any gravity effects during the fibre positioning either on the robot, xy carriage or the fibre module itself (after re-engineering the Large-Fibre Module there is little evidence to suggest there may be a problem here). It is definitely not advisable to move the telescope or rotator during the fibre setup.

For fields with good astrometry fiducial star acquisition is usually straightforward. Issuing the command:
`ICL> AFVIEWO XX`
where `XX` is the fibre or object number, will move the sky viewing mobile probe (attached to the robot) and position it looking skyward of fibre `XX`. Using a fiducial star near the field centre, the telescope should be moved in xy to centre the star in the mobile probe. Then a fiducial near the field edge should be selected and the star centred by moving the rotator only. This iterative process should continue using other fiducial stars as well.

After the acquisition process is complete the robot should be parked and powered down:
`ICL> AFSLEEP`
Parking the robot out of the field is not sufficient precaution as IR LED's are installed in AUTOFIB2 and will effect subsequent science exposures.

6.2.3 Calibrations

The AF2/WYFFOS Calibration Unit was installed at the broken-cassegrain focus of the WHT in summer 1999 and contains a range of lamps (Argon, Neon and Tungsten), and various astronomically useful filters. The system works by shining the light source onto the tertiary mirror which is then relayed to the fibres.

Depending on the requirements of the science project various calibrations are possible:

1. *Fibre transmission function.* This is basically a measure of the fibre-to-fibre response relative to an average fibre. It is usually determined by the instrument specialist soon after the instrument is installed at the telescope. The relation is derived by configuring the fibres into a circle (so they are all effected by the same level of vignetting within the field) (`AFALLCIRCLE`) and a twilight or exposure taken. At this time it is not thought that the transmission function can be derived sufficiently using the tungsten lamp in the calibration box as the field illumination is probably not uniform enough.

2. *Sky and offset sky exposures.* For almost any observation a sky observation for subtraction purposes is mandatory. Many observers use spare fibres for actual sky observations during the science observation. However, use of these spectra requires an accurate knowledge of the fibre transmission and also the vignetting function for the fibre distribution functions. If the transmission function is known (see above) then all that is necessary is to derive the vignetting function for the particular field which cannot be obtained from twilight flats with the same fibre configuration. This technique can work well and is especially important for observations taken when the sky brightness is changing during the exposure (e.g. moon rise/set). However, many observers prefer to take a series of exposures with the telescope offset from the field by say 30arcsec in different directions, obtaining a statistically significant number of counts. Median filtering these exposures can produce good sky spectra for each fibre.

3. *Wavelength calibration and flat-field exposures.* Recent tests with the AF2/WYFFOS Calibration Unit have shown that the prime field is well illuminated by the flat field lamp and differences in transmission between sky and lamp flats are only at the few percent level – sufficient for all but the most demanding uses of the instrument. Despite this, the main difficulty in wavelength calibration is found when using WYFFOS in echelle mode in order 7 ($\sim$3800Å) where lines from all lamps are weak and the fibre response low.

4. *Bias exposures.* Great care should be taken in obtaining bias exposures as the WYFFOS enclosure is not completely light tight and light can reach the detector without passing through the spectrograph optical system. Exposures are best taken at night.

6.2.4 Refraction effects and reconfiguring the field

Due to atmospheric refraction the positions of objects in the field will slowly shift as a function of zenith distance (z). Over the 1 degree field this is not a serious problem for objects close to the zenith. For objects with z <60 degrees

$\delta(z) \sim 60.4$ arcsec $\tan(z)$

which when $z < 60$ degrees, $\delta(z) < \pm 0.35$ arcsec which is acceptable. Thus, a field with dec = 30 could be tracked for about 6 hours (-3hr<HA<+3hr) without need for reconfiguration. However, this is not true for other declinations and observers should estimate the likely shifts for fields at z >40 degrees from the formula above and reconfigure as necessary. For large z (> 60 degrees) the formula given above should be replaced by:

$\delta(z) \sim 60.29$ arcsec $\tan(z) - 0.06688$ arcsec $\tan^3(z)$

6.2.5 Standards

After a field has been setup with the ICL software (in communication with the AF2 micro) the names and positions of targets are stored within the software *telescope noticeboard*. These items are used for various functions (e.g. fits headers in images). The ICL command AFOFFSET (see Appendix C.1 for more details) can be used to place a single object into almost any fibre. Note, as this command does not use a full distortion map of the prime focus then after offsetting the star will need to be re-acquired by the mobile probe and aligned with the fibre position. Extensive tests have shown this to be quite reliable and sufficiently accurate to offset from one side of the field to the other.

If an offset exists between the gripper center and the apparent center of the mobile probe, one can put a standard star under a fiducial fiber to mark the position of the gripper center on the mobile probe image. Then this mark should be used for further field or standard star acquisitions.

6.2.6 Quick-look data reduction and evaluation

Due to the nature of the WYFFOS slit, the curved spectra, and also the requirement to model and remove the scattered light within the spectrograph a dedicated multi-order reduction package should be used (see Chapter F).

6.2.7 Problems moving fibres: when to call engineering staff

In the event that the AUTOFIB2 micro is unable to determine the position of a fibre *for any reason*, the system will revert to a safe mode whereby it is unable to move any fibres until the missing fibre is recovered. The common occurrence of this is when a fibre is under illuminated, usually because of low fibre transmission. If the system claims to be unable to move any fibres until a fibre is recovered the user can issue the command:

```
ICL> AFRECOVER
```

and follow the prompts. The micro will proceed to check the positions for the last move of that fibre (the pickup and put down) and initiate a spiral search at each. If it successfully recovers the fibre you will be able to recommence moving fibres. If it is not successfully recovered the duty engineer should be called.

6.2.8 Other problems and known bugs

1) *Only a few header items appear in the file header*
As AUTOFIB2 data forms part of the ING archive it is necessary to have *header information for each fibre.* Consequently, AUTOFIB2 file headers are enormous with some 3000 items in each fits header! There are two possible reasons for grossly missing header items: a) the data analysis computer (lpss3) is not running the Sparc Real Time Display system (looks vaguely similar to SAOIMAGE) or b) the IRAF based WYFFOS data reduction package has not been started.

2) *Reductions immediately fail as the fibre module is not recognized or set to 'NONE'.* Try checking the value of the header parameter WYFFEED. If this is set as 'NONE' then reset it (by hand using the IRAF command HEDIT) to 'LARGE' or 'SMALL' depending which module you are using, e.g.
> hedit r*.imh WYFFEED 'LARGE' ver- update+ sho+

Appendix A

Setup procedures for AUTOFIB2

A.1 Laboratory based quality control

grid, straightness and repeatability tests

A.2 Sky based quality control

A.2.1 Astrometric fields

Astrometric fields are used to derive the prime focus distortion map for the WHT. Currently, APM scans of POSS II fields are used where the residuals in the astrometric solutions are small (<0.3 arcsec), but in the near future SLOAN astrometric fields will be available. The fields have been selected from regions of the sky that have recent plate material available and have a relatively uniform distribution of stars of a suitable brightness and a guide star available.

Configuration files for astrometric fields are stored in the solaris AUTOFIB account. To derive the prime focus distortion map a suitable file should be placed in the `[OBSERVER.AF2]` directory on the observing VAX and the telescope moved to the field centre coordinates and required position angle. Inspection of the configuration file will reveal that all objects it contains are classified as spare fiducial or alignment objects and that no fibre movements are requested. Setting up this field will merely result in the fiducial positions being loaded into the software telescope noticeboard. It is worth remembering that files cannot be shared between processes under a VAX, hence, if you are typing a file no other process has access to the file.

In terms of ICL commands:
`ICL> AFSETUP MAP08_1314.CFG` (attempt to setup .cfg file)
`ICL> AFPARKR` (park the AF2 robot out of the field)
`ICL> AFMOVP 150000` (moves the off-axis probe into the field)
If the acquisition is successful a guide star should be visible on the off-axis probe. As this object lies on the very edge of the 1 degree field its appearance will be comatic but sufficient for guiding which should be started. Before starting the mapping routine it is worth viewing some of the fiducials in order to ascertain the integration times required to give reasonable counts:

`ICL> AFVIEWO 901` (use the mobile probe to inspect fiducial object 901)
The field should then be acquired in the usual way (ie use x, y motions to centre fiducials near the field centre, and rotation to centre fiducials at the edge of the field). The mapping routine can then be started:
`ICL> AFMAP`
The routine will prompt the user for the number of centroids per object to attempt (three is usually sufficient), the integration time per centroid (2000 – 3000 milliseconds in good conditions), and the number of stars to measure.

The mobile probe will then move to the predicted position for each fiducial object and measure its position. This usually takes about one minute per star.

The mapping routine produces an output file called `[OBSERVER.AF2]ASTRO.AF2_DAT` which can be transfered to the solaris cluster for further analysis. This file is of the correct format for direct input into the STARLINK package ASTROM. For reliable results maps should be obtained for several astrometric fields and at several airmasses If the results of nine coefficient fits are consistent and significantly smaller than 0.5 arcsec it is possible that the prime field distortion map needs updating.

Data over several years indicates that the WHT prime focus field can be described by:

$$(17.643 \pm 0.001)x + (352.44 \pm 0.1)x^2 \ \mathrm{arcsec\,mm^{-1}}$$

The errors in these measurements are usually thought to be composed of the following: 0.3 arcsec from the poor off-axis guiding and 0.1 arcsec from the AUTOFIB2 robot encoders. The results have been remarkable consistent from run to run. Systematic variations have been found at the 0.1 – 0.2 arcsec level and are probably related to the radial distribution of stars in the map field (assuming all the APM scans have similar astrometric accuracy).

Appendix B

Setup procedures for WYFFOS

B.1 Alignment of the spectrograph

The WYFFOS spectrograph, based on a Baranne white pupil design, was installed on its own optical table in the GHRIL room on one of the Nasmyth platforms of the WHT during March 1995. This document describes the alignment procedure as determined at the initial assembly at RGO, Cambridge, through 1994, and modified in 1995. Effectively, WYFFOS is a kit of optical components which have to be placed to a high tolerance at certain positions on the optical table. WYFFOS works in two modes – reflection and transmission. Some components are common to both modes. Light is fed into WYFFOS via optical fibres of either 2.5 arcsecs or 1.5 arcsecs diameter, the output from the fibres into WYFFOS being slowed to f/8.2. In both modes, light from the curved slit is directed towards collimator one, where it is ... collimated onto the grating or grism. In reflection mode, the light is then reflected back through the collimator towards a concave relay mirror, where an image is formed close to the mirror. The relay mirror directs this image towards the camera, where it is re-imaged onto the internal CCD. In transmission mode, the light passes through the grism, then a second collimator, where it forms an image close to another concave relay mirror, which directs the image towards the turned round camera.

Those alignment aids specific to WYFFOS are kept in the WYFFOS cupboard on the Nasmyth level in the WHT dome, other items (for example lasers) can be found in the ISIS cupboards.

1. Three lasers, with 250 mm rails, mounts and posts having translation and height adjustments. Lasers need to be set to 235 mm above the optical table.

2. Two table extensions. Clamps to fit rails to extensions.

3. Three alignment posts (height set to 235mm).

4. Three 50 $\times$ 50 mm targets, perforated with a 2 mm diameter hole at centre, with free standing mounts.

5. ISIS grating (1200 lines mm^{-1}).

6. ISIS dummy grating.

7. Two light sources — white light and line emission.

8. Paper targets.

9. Templates for component baseplates.

In addition, you may need: Allen keys, steel rulers, internal micrometer, thread and a torch.

Refer to Figure 1XXX for details of the positioning of the components.

All components are positioned on the optical bench relative to one optical axis – the axis through the collimators. It makes sense to use a line of holes, as it is then possible to use the alignment posts to get a laser onto this axis. This axis was taken as the line of holes 16 holes – 425 mm – in from the edge of the optical bench. The projection of the pivot point for the camera on this axis (point X) was taken to be 1,425 mm from the telescope end of the bench, thus avoiding having either relay mirror one or two colliding with the spectrograph cover.

The slit axis was marked relative to the collimator axis: it crosses the collimator axis 60.4 mm further from the telescope end than X, and making an angle of 4.51 degrees with it. This is constructed by measurement; from Figure 1XXX, the slit axis is at a distance of 93.5 mm from the collimator axis point A_1, 1125.9 mm from point X. This makes the centre of the focal surface 1186.3 mm from A_1 i.e. 60.4 mm beyond X.

The pivot point for the camera is 326.5 mm away from the X – note the position of the hole at 325 mm from X.

The positions of the baseplates for the collimators, relay mirrors, slit unit and camera are defined using the templates taken from the setup at RGO Cambridge. These should enable positioning to better than 1 mm.

B.1.1 Relay Mirrors

Set two of the alignment posts on the collimator axis, one towards each end of the optical table, 425 mm from the edge of the optical bench. Mount one table extension onto the telescope end of the table, set up a laser with its beam going through the tips of the alignment posts. Do the same at the opposite end of the table. Make sure the rails are firmly clamped to the extensions. Put crosswires onto the front of the relay mirrors, marking their centres. Using the template from RGOC, position relay mirror 1 (R_1) onto the optical bench. The laser beam should hit R_1 7.5 mm from the centre of the mirror – i.e. 93.5 mm from the straight edge of the mirror. Measure the position from A_1 to X (put one alignment post in here temporarily) – this should be 1104.6 mm. Position the second relay mirror (R_2) in a similar fashion, except it should be 1100.2 mm from X. To tune the angles, set up a laser going from the transmission position, through the pivot point (326.5 mm from X) and onto the centre of R_2. Track this onto the centre of R_1 by tweaking the tilt of R_2. Then track the beam back onto the pivot point by tweaking the tilt of R_1. Fix the baseplates securely to the optical bench, and lock all adjusting screws on the kinematic mounts. The relay mirrors can then be removed *as a complete assembly in their mounts* by releasing the kinematic seats fixing them to their baseplates. The table extension at the door end of the optical table can be removed once the relay mirrors have been accurately positioned.

B.1.2 Collimators

Use the template from RGOC position collimator 1 (C_1) on the collimator optical axis. Remove R_1 from its baseplate, remove the alignment post from the telescope end of the optical bench, and replace it with a perforated alignment target. The laser beam should now be striking the pole of the front lens of C_1. Adjust the position of C_1 to get the back reflections and interference patterns coincident with the laser beam at the target. Replace R_1 and check the separation A_1 to the pole of C_1 – this should be 860.5 mm. If necessary, adjust by using blocks to allow the complete collimator baseplate to slide along the collimator axis, and further clamping blocks and slip gauges to enable controlled adjustment. Minor adjustment of the longitudinal position of C_1 can be achieved using the micrometer on C_1, but note this has a total range of 2.5 mm, so it is best to put this in the centre of its range, and adjust using the method described above. Remove the alignment post closest to the laser, and replace it with one of the perforated targets. Iterate on checking the separation between R_1 and C_1 and the back reflections until both are correct.

Use the same method to position collimator 2 (C_2). The separation between C_1 and C_2 should be 227.6 mm. Remove C_1 to do the squaring on. (note: both at RGOC and when aligned at LPO it was not possible to balance the back reflections and interference patterns from C_2 perfectly — see Figure ?XXX for details. Again, it is necessary to iterate between separations and back reflections. Clamp the baseplate securely to the optical bench, and lock all adjusting screws on the kinematic mounts.

B.1.3 Grating cell

This is positioned between the two collimators. The axis of rotation should be 100.0 mm behind the rear of C_1. To get it into this position, use the template brought from RGOC, remove C_1, square on to collimator axis laser (having installed the ISIS dummy grating in the cell), replace C_1, and check the separation, and squaring on. Clamp the baseplate securely to the optical bench, and lock all kinematic mounts. The grating encoder should read 0 milledgrees when the grating is squared on to the collimator axis laser.

B.1.4 Slit assembly

Install the second table extension at the telescope end of the optical table, in line with the slit axis. Use alignment posts to position another laser onto this axis (two holes on the bench should be on – or very close to – this axis. They accurately set the height of the slit axis laser and the direction to within a reasonable tolerance). Remove relay mirror R_1. With the collimator C_1 in position, the two laser beam should be coincident at the ISIS dummy grating surface.

Install the collimator target onto the front face of C_1 – positioning so that the collimator axis is centred onto the target. The position of the slit axis laser is shown as 25.0 mm offset from this. If necessary, adjust the position of the slit axis laser until it is. Iterate with the position of the slit laser so that its height from the pole at the input to the collimator and the coincidence at the dummy grating surface are correct. In addition, note the position of the slit axis where it passes the surface of R_1 – this should be 15 mm from the edge of R_1. When you are happy with the slit axis laser position, check that the laser beam tracks along the centre line of the R_1 when the grating cell is rotated.

Assume 150 μm (2.5 arcsecs) fibres. Install the complete slit assembly into its position using the template from RGOC. The fibres are grouped in modules of 9 fibres, with a total of 14 of these modules forming the curved slit.

Adjust the kinematic seats of the fibre support plate until it is parallel to the slit axis (best done by setting the gap between the fibre support plate and its mount to be the same all the way round in the first instance). set the slit translation (height) adjustment and slit focus (longitudinal) adjustment to midrange.

Fibre module 7 and 8 should be symmetrically placed about the slit axis. To set the slit height correctly however, we need to remove the fibre just above the centre line. Call this module 8, then module 7 (FM_7) is just below the slit axis. With the translation adjustment of the slit in mid range adjust the height of the slit unit from its baseplate until the slit laser beam just clears the top of FM_7. Adjust the complete baseplate until the laser beam is centred above the central column of holes in FM_7.

Illuminate FM_7 with white light, (it may be necessary to block off all but one fibre for the following). The f/8.2 output from the fibres should be centrally placed on the slit axis on the collimator target. Adjust the tilt until it is. Remove the collimator target from the front of C_1. Rotate the grating cell containing the dummy grating until the white light beams are directed back towards the slit assembly – they should come back to the position of the (removed) fibre module 8. The grating encoder reading for this autocollimation setting is approximately 6650 millidegrees. Illuminate the top fibre module. Its image should fall on the bottom fibre module. Adjust the rotation of the fibre plate until it is correct. Repeat with the lower fibre module. Check the position of FM_7 relative to the slit laser beam.

To set the slit to the autocollimation position, illuminate FM_7 with white light. With the slit focus at midrange, adjust the longitudinal position of the slit unit until the image is at best focus – position blocks to enable the complete slit unit to be slid along the optical axis. When this is achieved, iterate on the slit height and beam direction as before if necessary. Clamp the baseplate securely to the optical bench.

Illuminate the top fibre module. Its image should fall on the bottom fibre module. Check this is also in reasonable focus. Repeat for the bottom fibre module. Lock all adjusting screws on the kinematic mounts. It is best that the slit unit is in autocollimation with the slit translation and slit focus adjustments in midrange so that once the spectrograph is aligned any environmental changes are easily accommodated by these computer driven adjustments.

B.1.5 Camera

Mark the position for the camera in reflection mode using the template brought from RGOC. Insert an alignment post in the hole in the optical bench 1.5 mm away from the pivot point (i.e. 325 mm from X). One further hole in the optical table should be on the line joining R_1 to the pole of the camera corrector.

To mark up for transmission mode, firstly position a laser pointing from the transmission position, through the pivot point, and onto the centre of R_2. (If you remove the two collimators, and remove the dummy grating from its cell, this beam should hit the centre of R_1, and then go back through the pivot point.) This defines the optical axis into the camera in reverse. position targets on this axis, remove R_2 and send a laser back along this track from the position of R_2.

make sure the laser is firmly fixed to the optical table. Position the transmission mode baseplate on the bench using the template brought out from RGOC.

Position the camera on its in reflection mode baseplate, and measure the separation between R_1 and the camera. This should be 1257.9 mm. Note that the camera should be evacuated to get this measurement correct – the corrector moves inwards by 0.5 mm when it is under vacuum.

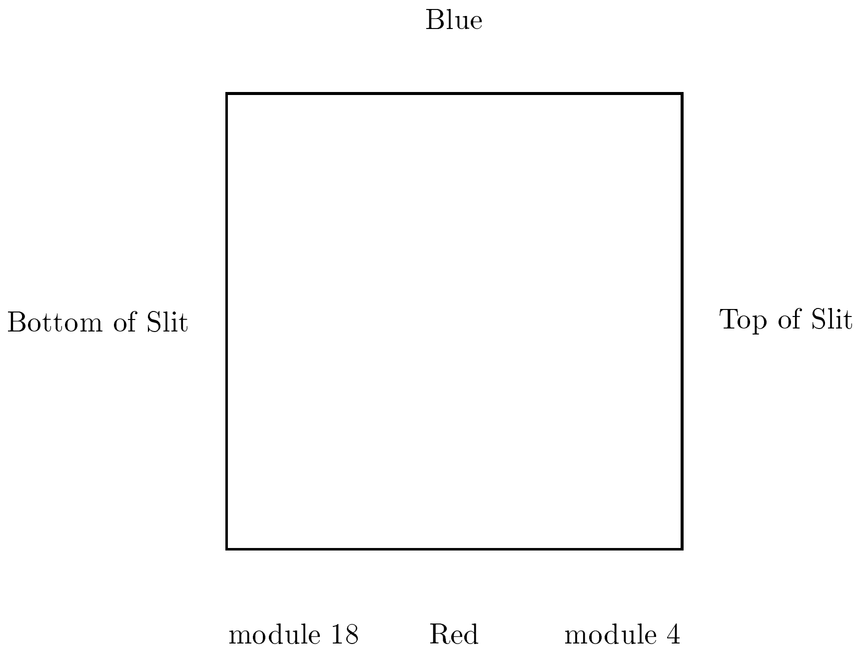
To square on the camera to the optical axis use the slit axis laser – rotate the dummy mirror in the grating cell to direct the beam to the centre of R_1. This should then pass through the alignment post positioned on the line joining R_1 to the camera corrector, and pass 1.5 mm from the post close to the pivot point. It may be necessary to tweak the alignment of R_1 to attain this. Insert a perforated target between R_1 and the camera. Assuming the camera has been aligned off-line (it should have been) the only alignment required now is to square on the complete camera assembly to the optical axis defind by the slit laser. This requires some judicious nudging – the complete camera weighs of order 125 kilos, and adjustment of the kinematic adjustment screws. After squaring on, check the R_1 to corrector spacing. Clamp the baseplate securely to the optical bench, and lock the adjusting screws on the kinematic mounts.

To position the camera for transmission mode, raise the camera from the reflection mode baseplate (using the documented procedure – see section ??), and position it on the transmission mode baseplate. Place a target on the laser beam coming from R_2 and square the camera on to it by nudging the complete assembly. Do not adjust the kinematic adjustment screws – it should be possible to achieve alignment without doing this, and if it isn't then something is wrong!. Check the spacing R_2 to the camera corrector – again, it should be 1257.9 mm. Clamp the baseplate securely to the optical bench.

B.1.6 Setting up the focus of the spectrograph

This section deals with the initial setup up of the camera, not to routine focussing after the initial setup, and involves checking the tilt of the CCD inside the camera. This entails adjusting three micrometers (A,B and C) at the back of the camera. Refer to ?? for details of routine focussing during use.

The Tek CCD has four readout amplifiers – one on each corner. The presentation of the image is determined by the amplifier being used for readout. In reflection mode, the current mapping from slit and grating to the chip is:–



At least three fibre bundles, one at each end of the slit and one near the centre, need to be illuminated with a comparison source – typically an argon lamp. Install the R1200R ISIS grating into the grating cell. It is okay to leave the grating cell at the change position (-25000 mdeg) to check the focus.

Set the slit focus to 0 (this should be the autocollimation position), slit translation to -3500 (this gets all of the start fibre on the chip), put in the right hartmann shutter, and take an exposure (1 second, say). Measure the y-centres of well exposed arc lines at the top, middle and bottom of the left hand, centre and right hand edge of the CCD - a total of nine points.

Open the right Hartmann shutter, and close the left one. Repeat the exposure and measure the y-centres of the same arc lines, and determine the difference (right-closed) - (left-closed).

Top of CCD

	-0.9	-0.2	-1.0	
Left edge of CCD	-0.4	$+0.5$	-0.5	Right edge of CCD
	-1.1	-0.2	-1.1	

Bottom of CCD

Note that the CCD surface is not flat – it is cut as a section from a spherical surface, so it is not possible to position the CCD to give (near) zero Hartmann shifts over the complete imaging area. The compromise was to adjust the micrometers to give a positive Hartmann shift at the centre of the CCD, and a negative (balanced) shift around the edge.

There is no serious degradation in performance if the shifts are within 0.3 of these value, either in tilt or piston, as the resolution of the spectrograph is limited by the fibre size (at least for the 2.5 arcsecond fibres). Having said this, it is wise to keep the shift in the centre close to $+0.5$. This should normally be accommodated using the slit focus.

If it should prove necessary to adjust the tilt of the CCD, then note the following:–

- Apply equal and opposite adjustments to B and C, leaving A alone changes the across fibre tilt,
- Apply equal adjustments to B and C, and double and opposite adjustment to A, changes the tilt in the dispersion direction,

Magnitude of the adjustments:-

- A piston of $+0.1$mm on A B and C changes the Hartmann shift (right-closed) $-$ (left-closed) by $+1.7$.
- In the across fibre direction, -0.1mm on B, and $+0.1$mm on C changes the tilt (left of chip) $-$ (right of chip) by $+0.4$.

- In the dispersion direction, −0.2mm on A, +0.1mm on B and C changes the tilt (top of chip) − (bottom of chip) by +0.4.

Note that normally after an adjustment in the dispersion direction, a small piston will be necessary, as the pivot is constrained by the copper cold finger, displacing the pivot point away from the chip centre.

Rotation is achieved by rotating the complete CCD ring, using a (small) rotation knob just below the pumping port on the camera. There is no accurate calibration!

To check rotation, use a continuum source instead of the calibration lamp. Find the line centre at the top and the bottom for a fibre at the centre of the imaging area of the CCD (i.e. column 512 + underscan region).

Very approximately, half a turn anticlockwise on the rotation knob changes the difference (top − bottom) by +1 pixel. This is very approximate – the link between the rotation knob and the CCD ring is a stranded cable, so is not at all consistent.

B.1.7 Camera Alignment

The camera was aligned to be self consistent prior to shipping to La Palma, and should not need re-aligning for some considerable time. The The camera is evacuated to approximately 10^{-6} millibars, and cryogenically cooled during use. If it is kept at its operating temperature (150 K) immediately following pump down, the outgassing rate is sufficiently low that the camera should not need repumping for three weeks or so. As the camera is kept below a few millibars at all times, and is not opened in normal service, the coating of the primary should remain in good condition for the lifetime of the instrument. The only possible reason the camera should need to be opened is either due to chip failure, or, most likely, for a chip upgrade. In this case, a minimal amount of checking of the alignment will be necessary, and the following procedure should be followed.

Assuming the camera is in the reflection position, is at room temperature, and vented to atmospheric pressure, then remove the relay mirror R−1. Set up a laser on the baseplate of R_1, adjusting it to get it squared on to the camera corrector. Remove the front end of the camera by removing the 16 M 6 bolts around the rim. Pull carefully away from the camera body in a straight line (to avoid damaging the CCD and field lens mounting rings). Disconnect the CCD connectors, disconnect the cold finger, disconnect the CCD rotation adjuster and remove the CCD ring, complete with the CCD.

To set the components back onto the optical axis, place a perforated target in front of the laser. Assuming there is no need to adjust the camera primary, then adjust the position of the field flattening lens to centre the back reflections and interference pattern onto the laser beam. Replace and reconnect the CCD mounting ring. Note that a sheet of indium foil is required between the cold finger from the CCD ring, and the cold finger from the cryostat, to improve the thermal contact. Replace the front end of the camera, making sure the springs are bearing correctly on the the CCD and field lens mounting rings, and there is no dirt or fleck on the ‘O’ rings sealing the front end to the main camera body. Pull the two together using the 16 M 16 bolts, making sure the front rim is pulled down squarely, Check that the back reflection from the camera corrector is still squared onto the laser.

The focus of WYFFOS will need to be checked after any dismantling of the camera. Experience has shown that it is possible to dismantle and rebuild the camera without disturbing the mutual alignment of the components.

B.1.8 Collimator Alignment

The collimator elements were mutually aligned in their cells at RGOC, and it is not envisaged that they will need to be realigned during the lifetime of the instrument.

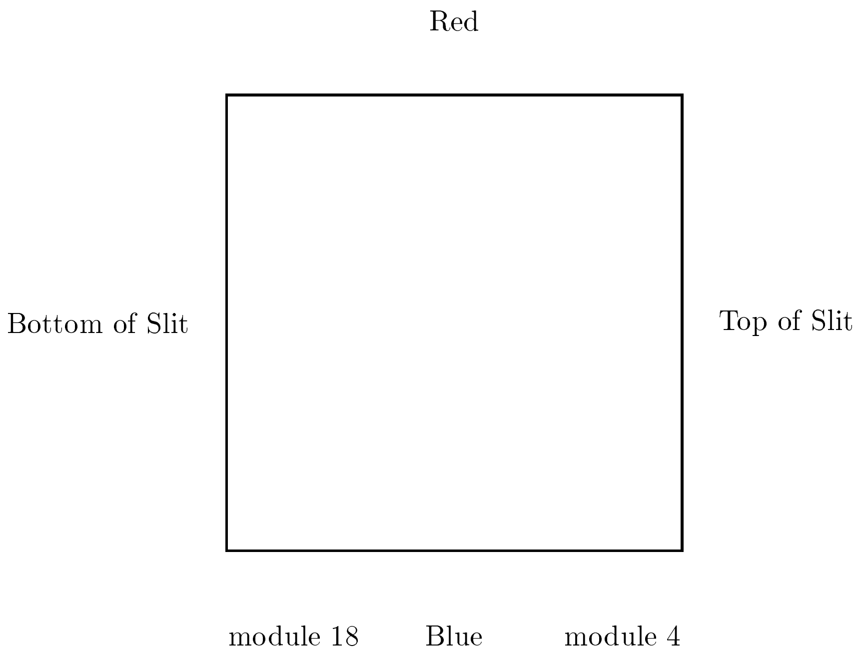
B.2 Changing from Reflection to Transmission Mode

Transmission mode is used for highest efficiency — and lowest resolution. From the specification,

> "with the fibre slit in the nominal position, the wavelength coverage is from approximately 4450 − 7400 Åin a half field (edge to centre). Peak blaze intensity is at about 5860 Å"

An order sorting filter is generally used to prevent overlapping of orders —typically a GG495, which transmits light from 4950 Åupwards, with 100% efficiency.

In transmission mode, the current mapping from slit and grating to the chip is:–



To change from reflection to transmission requires the use of the dedicated block and tackle found above the WYFFOS enclosure. At least two persons are required to carry out this procedure, one to handle the lifting, and the other to manipulate the camera.

1. Remove the top covers from the WYFFOS enclosure
2. Disconnect the camera cables (Hartmann shutters, system cables, nitrogen flush and nitrogen supply)
3. disconnect the CCD cables from the side of the WYFFOS enclosure
4. free the camera kinematic mounts, and lift the camera about 100 mm, and move it towards the door, away from the telescope end of the optical bench
5. rotate camera to face away from telescope end of the optical bench
6. move camera carefully to transmission position, taking care not to knock the valve on the pumping port
7. lower onto base
8. install grism into grating cell, with ruled surface away from telescope end of the optical bench
9. install collimator 2 into position – note it is out of balance, and will need clamping to its baseplate to stop it rocking
10. uncover relay mirror 2
11. reconnect camera leads, and CCD leads to enclosure
12. replace enclosure top covers

B.2.0.1 Routine Focus check – Transmission Mode

Assuming the the camera focus is fine in reflection mode (see section ??) then the transmission focus entails a possible shift in slit focus relative to that. Firstly set the grism to the correct angle – it is required to be at 5.2° to the collimator axis. I believe the grating encoding reads negative for all used angles, both in reflection and transmission, so the grating angle should be set to -5200 millidegrees. To check, the grating cell should be rotated clockwise viewed from above.

Illuminate the fibres with a line comparison source, and take exposures with firstly the right hartmann shutter closed, then with the left closed. measure the Hartmann shift in the centre of the chip, and adjust the slit focus to get the difference (right $-$ left) to be 0.5. Note that a change of $+1000$ in slit focus implies a change of -0.4 in hartmann shift.

B.3 Focusing and slit translation

Using an arc calibration source the fibres should be illuminated and arc lines recorded on the detector. The fwhm of arc lines should be mapped over the surface of the detector using the IRAF routine imexam or similar.

With current camera focus curvature over the tek detector fwhm 1.5 in centre and 2.5 at edges. focus v.stable and continuous adjustable over an arbitiary range of -6000 – 4000 units with the usual focus value somewhere near 0 – 500. It is usually recommended to set a focus to give slightly degraded fwhm in the central region (∼1.8) of the chip but improved resolution at the edges (∼2.2). This is usually achieved when a ring about half way towards the edge has the best focus (∼1.6).

Slit translation is variable as the slit unit is often removed from WYFFOS and should be setup by the instrument specialist prior to any science observations being attempted. easy to check: get a ff for all fibres and do an imexam cut check at edges in spatial direction on detector for any fibres close to edge.

B.3.1 Changing between reflection and echelle modes

Refer to drawing of grating/collimator area.

To change from normal reflection mode to echelle mode of operation requires the grating cell to be moved back 68mm from its normal position (away from collimator 1) and 2mm towards the access door.

The normal reflection position is defined by 3 definers; two are positioned either side of collimator 1, and the third is on the side of the grating cell nearest to the camera.

The echelle position is defined by 3 definers; one is between the proximity switches which register whether the grating is in normal or echelle position, the other two are on the long edge away from collimator 1. (The one furthest from the access hatch is positioned temporarily here, and will have to be moved at some future date to its correct position, which will require lifting the camera. Its current location would stop collimator 2 being installed and using the spectrograph in transmission mode.)

The collimator 2 position is defined by 3 definers; two are located on the side closest to the access hatch, and the third on the long edge away from collimator 1 (this one is positioned here temporarily, and will have to be moved at some future date to its correct position, which will require lifting the camera).

To go from normal to echelle:
There are 3 clamping brackets holding the grating cell baseplate to the table and these should be be removed. One is alongside the 'normal reflection mode' proximity switch, the second is on the long edge away from collimator 1 and the third is alongside the definer nearest to the camera.

With these removed, pull the camera back and towards you until it comes into contact with the echelle mode definers. Clamp the baseplate to the optical table; one clamp goes between collimator 1 and the grating cell, another on the long edge away from collimator 1, one alongside the 'echelle mode' proximity switch, and a fourth on the edge away from the access hatch, near the camera.

The 'echelle' grating is installed in the grating cell with the blaze towards the access hatch. It is operating in quasi-littrow mode when the grating angle is set to ∼-54000 mdegrees.

The limit on grating rotation in echelle mode is -65500 mdegrees; at this position the leading edge of the grating is just clear of collimator 1, and the trailing edge is just clear of the camera cryostat. A practical software limit should be set at ∼-65000 mdegrees, but check by inspection before implementing this.

The limit remains at -31000 mdegrees in normal reflection mode.

Currently, the order sorting filters should only be used in the filter cell closest to the slit (wfiltb). They are 4.12 - 6.10 mm thick, and would foul the barcode reader on wfilta (the barcode reader on wfiltb has been removed). The filter holders should be altered so this is not a problem.

The focus should be checked without filters in the beam - all orders are superimosed, but the low order lines are much brighter and dominate.

Appendix C

AUTOFIB2 software commands

C.1 ICL Control

Details of the commands available from ICL are given in this appendix. Commands may be issued in any mixture of upper and lower case. The parts of commands within parentheses are not required at the command line.

Command	Description
AFACQ(UIRE)	Acquire a field previously configured using AFSETUP
AFALLC(IRCLE)	Configure all fibres in the smallest circle
AFALLP(ARK)	Configure all fibres in their park positions
AFBACK(ILLUM)	Turn the back-illumination on or off
AFDISAB(LEFIBRE	Temporarily disable a fibre
AFENAB(LEFIBRE)	Enable a fibre disabled using AFDISABLEFIBRE
AFFIBM(ODULE)	Report the fibre module details
AFLIG(HTS)	Turn the inspection lights on or off
AFITER(ATIONS)	Set the fibre placement iteration count
AFLOADM(ODULE)	Locate each fibre in the fibre module
AFMAP	Perform a distortion map of the Prime Focus field
AFMON(MODE)	Turn monitor mode on or off
AFMOVF(IBRE)	Move a given fibre to a new position
AFMOVP(ROBE)	Move the off-axis probe to a new position
AFMOVR(OBOT)	Move the robot to a new position
AFOFFSETF(IBRE)	Offset a given fibre by an incremental amount
AFOFFSETR(OBOT)	Offset the robot by an incremental amount
AFOFFSET(TEL)	Perform a telescope offset to a given fibre
AFPARKR(OBOT)	Park the AF2 robot
AFPARKF(IBRE)	Move a given fibre to its park position
AFQUAD(RANT)	Move the robot to a quadrant around its current position
AFRECOVER(FIBRE)	Recover the position of the last fibre moved
AFSETUP	Configure AF2 to a specified field
AFSLEEP	Park the robot and shut down AF2 safely
AFTELLF(IBRE)	Report fibre information for a given fibre
AFTELLP(OS)	Report fixed autoguider probe and robot positions
AFTELLS(TAT)	Report the AF2 status
AFTOL(ERANCE)	Set the fibre positioning tolerance
AFVIEWF(IBRE)	Move the robot to view a given fibre
AFVIEWO(BJECT)	Move the viewing probe to view a given object
AFVIEWS(KY)	Move the viewing probe to view a given sky position
AFWAKE	Start up the AF2 instrument

C.1.1 AFACQUIRE

Acquire a field previously configured using AFSETUP.

Acquire or re-acquire a configured field. Fiducial objects defined in the configuration file <field>.CFG are used with the mobile autoguider probe to calculate the field shift and rotation to be applied to the telescope to optimise the accuracy of the projected fibre placement on the sky. AFACQUIRE advises the maximum number of fiducial objects available for acquisition. The user supplies the autoguider integration time, the number of centroids to be made for each fiducial object and the number of fiducial objects to be used for acquisition. Users may choose any number of objects to be used in the measurement, subject to the minimum needed for the fit (using SLA_FITXY) and the maximum number available.

ICL Command Format:

AFACQ(UIRE) – Acquire a field previously configured using AFSETUP

C.1.2 AFALLCIRCLE

Configure all available fibres in the smallest circle.

This command places all the fibres in a circle of the smallest possible radius. This fibre radius is ... Before attempting to move any fibres, the command checks whether an AFSETUP, AFALLCIRCLE or AFALLPARK is in already progress and takes appropriate action. The fibre back-illumination is switched on before any fibres are moved and switched off again on completion. The robot is also parked on successful completion.

The optional iteration count given on invocation of the AFALLCIRCLE command is only used for the circle fibre placement. On completion or abort the initial fibre iteration count is set.

ICL Command Format:

AFALLC(IRCLE) <N> – Set iteration count to N for the fibre placement
AFALLC(IRCLE) – Use a default iteration count of 1

C.1.3 AFALLPARK

Place all available fibres at their park positions.

This command places all the fibres at their park positions. This fibre radius is ... Before attempting to move any fibres, the command checks whether an AFSETUP, AFALLCIRCLE or AFALLPARK is in already progress and takes appropriate action. The fibre back-illumination is switched on before any fibres are moved and switched off again on completion. The robot is also parked on successful completion.

The optional iteration count given on invocation of the AFALLPARK command is only used for the park fibre placement. On completion or abort the initial fibre iteration count is set.

ICL Command Format:

AFALLP(ARK) <**N**> – Set iteration count to N for the fibre placement

AFALLP(ARK) – Use a default iteration count of 1

C.1.4 AFBACKILLUM

Turn the back-illumination on or off.

This command turns the fibre back-illumination onn or off. If no parameter is given, the current state of the fibre back-illumination is reported.

ICL Command Format:

AFBACK(ILLUM) <**ON**|**OFF**> – Turn the fibre back-illumination ON or OFF

AFBACK(ILLUM) – Report the current back-illumination state

C.1.5 AFDISABLEFIBRE

Temporarily disable a fibre.

The given fibre number, N, is marked as disabled. This temporarily disables the specified fibre so that it is not configured in future Setups. The fibre will remain in its current position unless parked. It may be enabled again using the command AFENABLEFIBRE. If no parameter is given, the user is prompted for a fibre number.

ICL Command Format:

AFDISAB(LEFIBRE) <**N**> – Disable fibre N

C.1.6 AFENABLEFIBRE

Enable a fibre disabled using AFDISABLEFIBRE.

The disabled fibre, N, is marked as enabled. This enables the specified fibre to be configured in future Setups. This command only works on fibres disabled using the AFDISABLEFIBRE command; fibres disabled for operational reasons can only be re-enabled from the AF2 engineering interface. If no parameter is given, the user is prompted for a fibre number.

ICL Command Format:

AFENAB(LEFIBRE) <**N**> – Enable fibre N

C.1.7 AFFIBMODULE

Report the fibre module details.

Reports the status details of the currently installed fibre module. The count of disabled fibres covers temporarily and permanently disabled (or missing) fibres. The module ID will be the identity returned by AF2 in the set NONE|SMALL|LARGE|SPECIAL|UNKNOWN.

Items reported:

- Module ID
- Total fibres
- Number of objects
- Number of fiducials
- Number of fibres disabled

ICL Command Format:

AFFIBM(ODULE) – Report fibre module details

C.1.8 AFLIGHTS

Turn the inspection lights on or off.

This command turns the AF2 inspection lights within the body of the instrument on or off. If no parameter is given, the current state of the inspection lights is reported.

ICL Command Format:

AFLIG(HTS) <ON|OFF> – Turn the inspection lights on or off
AFLIG(HTS) – Report the inspection light state

C.1.9 AFITERATIONS

Set the fibre placement iteration count.

The iteration count is the maximum number of times the AF2 robot places a fibre, measures its position and compares this position with the placement tolerance (specified by the AFTOLERANCE command). If no parameter is given, the value of the current iteration count is given.

ICL Command Format:

AFITER(ATIONS) <N> – Set the iteration count to N
AFITER(ATIONS) – Report the current iteration count

C.1.10 AFLOADMODULE

Locate each fibre in the fibre module.

This command performs a check on the position of each fibre in the fibre module. The fibre position in the AF2 microcomputer are then updated. The command will check the position of disabled fibres because they may be re-enabled at some point and subsequently used.

ICL Command Format:

AFLOADM(ODULE) – Locate each fibre in the fibre module

C.1.11 AFMAP

Perform a distortion map of the Prime Focus field.

Construct a distortion map of the Prime Focus field using a standard set of star positions.

ICL Command Format:

AFMAP – Map the Prime Focus distortion

C.1.12 AFMONMODE

Turn monitor mode on or off.

This command turns the AF2 monitor mode on or off. If no parameter is given, then the current monitor-mode state is reported.

ICL Command Format:

AFMON(MODE) <**ON**|**OFF**> – Set monitor mode on or off
AFMON(MODE) – Report the current monitor-mode state

C.1.13 AFMOVEFIBRE

Move a given fibre to a new position.

This command moves a given fibre, identified by its pivot number N, from its current position to a position (X,Y). The position is given as an integer number of microns relative to the AF2 field centre. The fibre back-illumination is turned on before the placement and turned off afterwards.

ICL Command Format:

AFMOVF(IBRE) <**N**> <**X**> <**Y**> – Move fibre N to position (X,Y)

C.1.14 AFMOVEPROBE

Move the off-axis probe to a new position.

This command moves the off-axis (fixed autoguider) probe to the given position, relative to the origin of the probe. Units of the movement are in microns. On completion, the new position of the probe is reported. If no parameter is given, the current probe position is reported.

ICL Command Format:

AFMOVP(ROBE) <X> – Move probe to X microns
AFMOVP(ROBE) – Reports the current probe position

C.1.15 AFMOVEROBOT

Move the robot to a new position.

This command moves the robot gripper carriage to a new (X,Y) position. Co-ordinates are given integer microns relative to the AF2 field centre. On completion, the new robot position is reported. If no parameters are given, the current robot position is reported.

ICL Command Format:

AFMOVR(OBOT) <X> <Y> – Move the robot to position (X,Y)
AFMOVR(OBOT) – Reports the current robot position

C.1.16 AFOFFSETFIBRE

Offset a given fibre by an incremental amount.

This command offsets the fibre, specified by the pivot number N, by an amount (dX, dY) microns relative to its current position.

ICL Command Format:

AFOFFSETF(IBRE) <N> <dX> <dY> – Offset position of fibre N by (dX,dY)

C.1.17 AFOFFSETROBOT

Offset the robot by an incremental amount.

This command offsets the robot by an amount (dX,dY) microns relative to its current position. On completion, the robot carriage position is reported.

ICL Command Format:

AFOFFSETR(OBOT) <dX> <dY> – Offset robot position by (dX,dY)

C.1.18 AFOFFSETTEL

Perform a telescope offset to a given fibre

The command will move the prime focus rotator to the specified sky position angle and prompt the user to centre the specified object at the field centre before performing the offset. The command will then move the telescope to centre the object in the specified fibre and move the mobile probe to view the object above the fibre for acquisition. SOURCE is the TCS User Catalogue name of the object used for the offset.

ICL Command Format:

AFOFFSET(TEL) <SKYPA> <SOURCE> <FIBRE> – Move the rotator to SKYPA, then offset the telescope to position SOURCE in fibre number FIBRE

C.1.19 AFPARKROBOT

Park the AF2 robot.

Park the robot carriage out of the field.

ICL Command Format:

AFPARKR(OBOT) – Park the robot carriage safely

C.1.20 AFPARKFIBRE

Move a given fibre to its park position.

Places the specified fibre in its park position.

ICL Command Format:

AFPARKF(IBRE) <N> – Park fibre N

C.1.21 AFQUADRANT

Move the robot to a quadrant around its current position.

Offsets the robot into the specified quadrant.

ICL Command Format:

AF2QUAD(RANT) <N> – Move robot to quadrant N

C.1.22 AFRECOVERFIBRE

Recover the position of the last fibre moved.

This command instructs AF2 to recover the last fibre used if the gripper couldn't pick it up properly, or if the fibre was dropped during a move. The command MUST be used immediately a fibre is "lost" in this way, otherwise unexpected fibre placement problems will occur, and fibres could be damaged. The command causes AF2 to inspect the immediate area where the fibre was last known to be. The fibre position is updated as soon as it is found. Any command aborted as the result of a fibre being "lost" can be repeated as soon as the fibre has been recovered. If AF2_RECOVERFIBRE fails to recover the fibre, expert help must be sought before proceeding with any fibre moves.

ICL Command Format:

AFRECOVER(FIBRE) – Recover the position of the last fibre used

C.1.23 AFSETUP

Configure AF2 to a specified field.

The new field to be configured is defined by the specified field name; the objects to which fibres are to be assigned will have been decided using the CONFIGURE utility and saved in a file <NEW_FIELD>.CFG. The set-up uses the Prime Focus distortion correction defined in the file WHT_AF2DATA_DIR:WHT_PRIME.DAT, and the fibre data appropriate to the installed fibre module from the file WHT_AF2DATA_DIR:<ID>_FIBRES.DAT, where ID is the fibre module ID (LARGE|SMALL).

ICL Command Format:

AFSETUP <NEW_FIELD> – Set-up the field in <NEW_FIELD>.CFG

C.1.24 AFSLEEP

Park the robot and shut down AF2 safely.

Put AF2 into a dormant state by parking the robot, and turning the power off. Before AF2 can be used, it must be re-awakened using the AF2_WAKE command.

ICL Command Format:

AFSLEEP – Put AF2 into a safe, dormant state

C.1.25 AFTELLFIBRE

Report fibre information for a given fibre.

Report fibre-related information for the specified fibre from AF2's noticeboard. Noticeboard information is updated.

ICL Command Format:

AFTELLF(IBRE) <N> – Return fibre data for fibre N

C.1.26 AFTELLPOS

Report fixed autoguider probe and robot positions.

Report probe- and robot- related information from AF2's noticeboard. The noticeboard is updated with current status from AF2.

ICL Command Format:

AFTELLP(OS) – Return probe and robot status

C.1.27 AFTELLSTAT

Report the AF2 status.

Information returned includes: Power, Robot, Probe, Back illumination, Inspection light, Fibre module, Temperature. The noticeboard is updated by this command with current status from the AF2 instrument.

ICL Command Format:

AFTELLS(TAT) – Return AF2 status

C.1.28 AFTOLERANCE

Set the fibre positioning tolerance.

Set AF2's robot positioning tolerance in units of microns. Reports tolerance and maximum iterations afterwards, or if no parameter is supplied.

ICL Command Format:

AFTOL(ERANCE) <X> – Sets positioning tolerance to X microns
AFTOL(ERANCE) – Report tolerance and iterations

C.1.29 AFVIEWFIBRE

Move the robot to view a given fibre.

Move the fibre positioning robot to view the specified fibre with the in-built fibre viewing system. Command reports robot carriage position on completion.

ICL Command Format:

AFVIEWF(IBRE) <N> – View fibre N with the TV viewing system

C.1.30 AFVIEWOBJECT

Move the viewing probe to view a given object.

Position the mobile (sky viewing) probe at the (X,Y) of the specified object and report its final position. The object number determines whether configured objects (with an assigned fibre) or fiducial objects are viewed. Configured objects are numbered 1 <= N <= Number of fibres in module Fiducial objects are numbered 901 <= N <= 990 (for fiducials 1..90)

ICL Command Format:

AFVIEWO(BJECT) <N> – Move sky viewing probe to object N

C.1.31 AFVIEWSKY

Move the viewing probe to view a given sky position.

Position the mobile (sky viewing) probe at the specified (X,Y) and report its final position. Position data is in integer microns relative to the field centre.

ICL Command Format:

AFVIEWS(KY) <X> <Y> – Move sky viewing probe to position

C.1.32 AFWAKE

Start up the AF2 instrument.

Make AF2 available for use by turning on the power, initialising the off-axis probe and initialising the robot. Also reports the current system status on completion. Used whenever AF2 has been powered down by the AF2_SLEEP command.

ICL Command Format:

AFWAKE – Make AF2 ready for use

C.2 Engineering commands

The following engineering commands are available at the ICL prompt. These commands are not intended for normal use by astronomers; great care should therefore be taken if these commands are used.

Command	Description
AF2	Shorthand for OBEYW AF2 ...
AF2_BEGIN	Initial start-up of the AF2 software
AF2_CANCEL	Cancel an AF2 action
AF2_DEFINE	Load the AF2 procedure definitions
AF2_END	Shut down the AF2 software
AF2_GRIPPER	Set gripper state to open or closed
AF2_INIT	Initialise a given AF2 mechanism
AF2_LOAD	Re-load AF2 D-task if not already loaded
AF2_SIMULATE	Simulate the AF2 hardware using UCP utility
AF2_START	Start the AF2 ICL software initialisation
AF2_UPDATE	Update the AF2 status information
SET_MICRO	Set the UNET name of the AF2 microprocessor system

C.2.1 Dtask actions

These are the D-task actions for AF2:

D-task action	AF2/**UNET mnemonic**	**Supported sub-actions**
AXES_DATA	PER	MOVE, ISTAT
BACK_ILLUM	BCK	ISTAT, DSTAT
FIBRE_UPDATE	FIB	MOVE, ISTAT, DSTAT
HEALTH_MONITOR	HMS	ISTAT
INSPECTIONLIGHT	LGT	MOVE, ISTAT, DSTAT
FIBRE_MODULE	MID	ISTAT
MONITOR_MODE	MON	MOVE, ISTAT, DSTAT
NET_RESET	NET	MOVE
POWER	POW	MOVE, ISTAT, DSTAT
PROBE	PRO	INIT, STOP, MOVE, ISTAT, DSTAT
RESET	RES	MOVE
ROBOT	ROB	INIT, STOP, MOVE, ISTAT, DSTAT
SETUP_TARGET	CON	STOP, MOVE, ISTAT, DSTAT
TEMPERATURE	TMP	ISTAT
COMMAND_MODE	SRC	ISTAT

C.2.2 AF2

This command is a shorthand for "OBEYW AF2" and it can be given a variable number of arguments. Parameters P1 and P2 correspond to the ACTION and the SUB_ACTION respectively and are obligatory. Other parameters P3-P5 are optional depending on the command issued.

ICL Command Format:

AF2 P1 P2 P3 P4 P5 – Issue AF2 OBEYW P1 P2 P3 P4 P5

C.2.3 AF2_BEGIN

C.2.4 AF2_CANCEL

C.2.5 AF2_DEFINE

This command loads the AF2 procedure definitions

ICL Command Format:

AF2_DEFINE – Load AF2 procedure definitions

C.2.6 AF2_END

C.2.7 AF2_GRIPPER

Sets the state of the AF2 robot gripper jaws or, if no parameter is given, reports whether the jaws are open or closed.

ICL Command Format:

> **AF2_GRIPPER <OPEN|CLOSE>** – Open or close gripper jaws
> **AF2_GRIPPER** – Report the gripper state

C.2.8 AF2_INIT

C.2.9 AF2_LOAD

C.2.10 AF2_SIMULATE

C.2.11 AF2_START

This command is issued by the AF2 start-up sequence to load and start the D-task and I-tasks. Checks are made to see if tasks are already present before loading is attempted. The obligatory D-task UNEX action is started to check for incoming 80x messages, and the HEALTHMONITOR action is also started. The command _must_ be called supplying the name of the UNET destination for AF2 messages. Also used by the AF2_SIMULATE command.

ICL Command Format:

> **AF2_START <UNET_destination>** – Start AF2 system tasks and initialise

C.2.12 AF2_UPDATE

C.2.13 SET_MICRO

C.3 Set and Show commands

These commands are available from the D-task alone, to set and show status information relevant to the D-task interface.

ICL Command Format:

> **AF2 SET <PARAMETER> <VALUE>** – Set named D-task parameter to <VALUE>

AF2 SHOW <PARAMETER> – Show named D-task parameter

Both give additional help if invoked with a <PARAMETER> value of HELP.

AF2 SET HELP – Obtain list of SET'table parameters
AF2 SHOW HELP – Obtain list of SHOW'able parameters

The SET and SHOW keywords cannot be abbreviated.

C.4 Errors

The following error codes are returned by AF2 and are handled by the AF2 D-task.

C.4.1 Mechanism errors

Error Code	**Error Message**
BADFIDUCIAL	<Fiducial object number out of range for current target>
BCKILLUMFAIL	<Error turning back illumination on or off>
CENTROIDFAIL	<Failed to complete centroid issued from eng. interface>
CONCGPFAIL	<Cannot move from existing to new configuration directly>
CONCONFLICT	<Conflicting or illegal info in .FIB file e.g. collision>
CONFIBMOVERR	<Can't configure missing or disabled fibre>
CONFIBREADERR	<Error reading fibre data from .FIB file>
CONHEADERERR	<Error(s) in .FIB file header>
CONNXTFLDERR	<Error opening internal file NEXTFIELD.DAT on AF2>
CONSETUPERR	<Unspecified error while configuring future target field>
CONSTOPPED	<SETUP initiated by CONfigure command has been aborted>
CONTARGETMISSING	<Target file (.FIB) is missing or otherwise unavailable>
FIBERR	<Fibre status can't be changed>
FIBREINJAWS	<Fibre stuck in gripper jaws - seek assistance now>
FIBUNAVAILABLE	<Fibre broken, missing or disabled>
ILGLFIBPOS	<Requested fibre position is illegal or beyond limits>
INSPLIGHTFAIL	<Error turning inspection lights on or off>
INVFIBNO	<Fibre number is out of range for installed fibre module>
LOSTFIBRE	<Fibre position unknown - seek assistance now>
LOWERTOPLATEFAIL	<Failed to lower fibre to field-plate during put-down>
MOTORSDISABLED	<Motors not enabled>
MOTORFAIL	<Error turning motors on or off>
MOVETOPLATEFAIL	<Failed Z move to field-plate during pick-up>
NOAIRPRESS	<Compressed air is off, or has low pressure>
NOBACKILLUM	<Back-illumination is required for SETUP or moving fibre>
NOFIBINFO	<Fibre data not yet loaded>
NOFIBMODULE	<Can't enable motors if no fibre module is installed>
NOFIBREVISIBLE	<Cannot see fibre to pick up>
NOFIBTOPLACE	<Cannot place non-existent fibre>
NOKNOWNFIBRE	<No known fibre to pickup at current position>
NOPOWER	<No instrument power>
NOSECONDFIBRE	<Cannot pick up second fibre button>

Mechanism errors continued ...

Error Code	**Error Message**
POWERFAIL	<Error turning instrument power on or off>
PREVERROR	<Can't obey request because of a previous error>
PROILGLMV	<Moving the off axis probe would cause collision>
PROINITFAIL	<Error initialising off axis probe>
PRONEEDSROBINIT	<Probe can't be moved without initialising robot>
PRONINIT	<Probe can't be moved; please initialise probe>
PROLIMIT	<Probe is in limit switch>
PROPOSERR	<Off axis probe position error>
ROBBADCENTROID	<Failed to centroid fibre image during putdown>
ROBFIBMOVILGL	<Illegal move while carrying fibre>
ROBGRIPTOOLOW	<Gripper too close to plate to move robot>
ROBILGLMOV	<Robot move would cause collision>
ROBINITFAIL	<Error initialising robot>
ROBLIMIT	<Robot is in limit switch>
ROBLOADFAIL	<Failed to load or recover fibre>
ROBLOST	<Robot position not known; robot is uninitialised>
ROBMOVFIBERR	<Error moving fibre>
ROBNEEDSPROINIT	<Must initialise probe before initialising robot>
ROBNINIT	<Robot can't be moved; please initialise robot>
ROBOFFERR	<Requested offset puts robot beyond X or Y limit>
ROBPARKERR	<Error parking robot>
ROBPICKUPERR	<Error picking up fibre>
ROBPUTDWNERR	<Error placing fibre>
ROBSTUCK	<Can't extract robot from limit switch>
ROBTPOSERR	<Robot theta position error>
ROBXPOSERR	<Robot X position error>
ROBYPOSERR	<Robot Y position error>
ROBZPOSERR	<Robot Z position error>
SERVOINACTIVE	<Servo amplifier is not active or has no power>
TEMPOUTRANGE	<Internal temperature is out of range>
TIMEOUT	<Mechanism timed out within AF2>
UNUSED	<AF2 has returned an unrecognisable error code>

C.4.2 Command errors

Error code	**Error Message**
COMMINVFMT	<Command rejected - Invalid format>
COMMINVFUNC	<Command rejected - Invalid function>
COMMINVPAR	<Command rejected - Invalid parameter>
COMMMONMODFUL	<Command rejected - Monitor mode list full>
CANCELLED	<Command has been cancelled>
INTERLOCKED	<Mechanism is in interlocked state>
MULTERRS	<Multiple errors have occurred>
NDNOTENT	<Node name not entered on monitor mode list>
PAROUTOFRANGE	<Command rejected - Parameter out of range>
TASKACTIVE	<Mechanism is busy>
UNDEFERROR	<Unexpected error code returned>
WRONGCMDMODE	<Micro is unable to accept remote commands in LOCAL mode>

Appendix D

WYFFOS software commands

D.1 ICL Control

Details of WYFFOS commands available from ICL are given in this appendix. Commands may be issued in any mixture of upper and lower case. Optional characters in the command names are shown in brackets.

Command	**Description**
WGRAT(ING)	Set grating to specified angle
WCENWAVE	Set grating for specified central wavelength
WFILT(ER)	Move named filter into the beam
WSLITF(OC)	Set slit focus position
WCAL(IB)	Switch calibration lamps on/off
WHART(MANN)	Set Hartmann shutters
WNITRO(GEN)	Control nitrogen flush
WFIB(ILLUM)	Control AF2 fibre back illumination
WSLITT(RAN)	Set slit translation position
WCHANGE	Change grating/filter (Specify names)
WFILTERA	Move filter slide A
WFILTERB	Move filter slide B
WSETFOC(US)	Control filter focus compensation
WBARCODES	Enable/disable barcode reading

D.1.1 WGRAT(ING)

Move the WYFFOS grating to the specified angle. The specified setting accuracy of the grating is +/- 0.01 deg.

ICL Command Format:

WGRATING <angle> Where angle is a real number of degrees.

Example:
`ICL> WGRATING 7.81` (set grating to angle 7.81 degs)

D.1.2 WCENWAVE

Set the WYFFOS grating to the angle corresponding to the specified central wavelength in a particular order (default first order).

ICL Command Format:

WCENWAVE <wavelength> <order> Wavelength in Angstroms.

Examples:
`ICL> WCENWAVE 5600 5` (Set the grating to the angle corresponding to a central wavelength of 5600 Angstroms in order 5 echelle mode)

`ICL> WCENWAVE 5600` (Set the grating to the angle corresponding to a central wavelength of 5600 Angstroms in reflection mode)

D.1.3 WFILT(ER)

This command is used to move the named filter into the beam. The filter slide that contains the named filter is automatically selected - there is no need to specify which slide contains the filter. If the parameter OUT is given, both filter slides are moved to the OUT position.

ICL Command Format:

WFILTER <filter name> or OUT

If automatic filter thickness focus adjustment is enabled, the slit focus will be adjusted to compensate for the filter moving in or out of the beam.

Example:
`ICL> WFILTER RG630` (Move the filter RG630 into the beam)

D.1.4 WSLITF(OC)

This command sets the WYFFOS slit focus to a specified position in microns.

ICL Command Format:

WSLITFOC <position> Position in microns

If automatic filter thickness focus adjustment is enabled, any subsequent filter moves will cause the slit focus to be adjusted automatically.

Instead of the position, the parameter INIT may be given to initialize (datum-set) the slit focus mechanism.

Example:
`ICL> WSLITFOC 1678` (Sets the slit focus to 1678 microns)

D.1.5 WCAL(IB)

This command is used to switch the specified (numbered) comparison lamp ON or OFF. (The use of comparison lamp names is not yet supported)

ICL Command Format:

WCALIB <lamp number> <state>

The lamp number must be in the range 1 to 4. The lamp state is specified as either ON or OFF.

Example:
`ICL> WCALIB 1 ON` (Switch comparison lamp number 1 ON)

D.1.6 WHART(MANN)

This command is used to set the WYFFOS camera Hartmann shutters to the required configuration. The shutter configurations are specified as one of a set of four strings <L, R, LR, OUT> as described below.

ICL Command Format:

WHARTMANN <shutters state> shutters-state as listed below

Defined Hartmann shutter configurations are as follows:

L	Left Hartmann shutter	IN,	Right shutter	OUT
R	Right Hartmann shutter	IN,	Left shutter	OUT
LR	Both Hartmann shutters	IN		
OUT	Both Hartmann shutters	OUT		

Examples:
`ICL> WHARTMANN L` (move Hartmann shutter Left in, Right out)
`ICL> WHARTMANN OUT` (move both Hartmann shutters out)

D.1.7 WNITRO(GEN)

This command is used to switch the WYFFOS camera nitrogen flush facility ON or OFF.

ICL Command Format:

WNITROGEN <flush state>

The flush state is specified as ON or OFF.

Example:
`ICL> WNITROGEN ON` (Switch nitrogen flush ON)

D.1.8 WFIB(ILLUM)

This command is used to switch the AF2 fibre back illumination lamp on or off.

ICL Command Format:

WFIBILLUM <illum state>

The illumination state is specified as ON or OFF.

Example:
`ICL> WFIBILLUM ON` (Switch AF2 fibre back illumination lamp ON)

D.1.9 WSLITT(RAN)

This command sets the WYFFOS fibre slit to a specified position in microns using the slit translation drive.

ICL Command Format:

WSLITTRAN <position> Position specified in microns

Alternatively, the parameter INIT may be given to initialize (datum-set) the slit translation mechanism.

Example:
`ICL> WSLITTRAN 3291` (Sets the fibre slit position to 3291 microns)

D.1.10 WFILTERA

This command is used to move the filter in filter slide A into or out of the beam. It is not possible to use the name of a filter with this command : the named filter slide is simply moved to the In or Out position.

ICL Command Format:

> **WFILTERA** <slide position>

The filter slide position is specified as IN or OUT

Examples:
`ICL> WFILTERA IN` (Move filter slide A into the IN position)
`ICL> WFILTERA OUT` (Move filter slide A into the OUT position)

D.1.11 WFILTERB

This command is used to move the filter in filter slide B into or out of the beam. It is not possible to use the name of a filter with this command : the named filter slide is simply moved to the In or Out position.

ICL Command Format:

> **WFILTERB <slide position>**

The filter slide position is specified as IN or OUT

Examples:
`ICL> WFILTERB IN` (Move filter slide B into the IN position)
`ICL> WFILTERB OUT` (Move filter slide B into the OUT position)

D.1.12 WSETFOC(US)

When a WYFFOS filter is moved into or out of the beam, the slit focus may be adjusted to compensate for an alteration in filter thickness. Automatic compensation when a filter is changed is enabled using this command.

ICL Command Format:

> **WSETFOCUS** <state> or <focus value>

Automatic compensation can be switched on or off by specifying the state as either ENABLE or DISABLE.

If a numeric value is supplied then this will switch on focus compensation and set the slit focus to the specified position (units are microns).

Examples:

```
ICL> WSETFOCUS ENABLE
WYFFOS Slit focus compensation is now ON
ICL> WSETFOCUS DISABLE
WYFFOS Slit focus compensation is now OFF
ICL> WSETFOCUS 3300
WYFFOS Slit focus compensation is now ON
WYFFOS Slit focus has been set to 3300
```

D.1.13 WBARCODES

This command enables or disables the use of WYFFOS filter barcodes.

ICL Command Format:

WBARCODES <state> Where state is YES or NO

If the value given is YES then filter barcodes will be read when using the WCHANGE command. If NO then the barcodes will not be read - the user simply inputs the filter names directly as prompted.

D.1.14 Grating and Filter Names

The names of filters and the grating currently loaded in WYFFOS are defined using the command WCHANGE. Grating barcodes are not supported and the use of barcodes on the filters is optional - without them the user simply defines names for each filter currently loaded. The currently available filters and gratings are given in Sections 3.3 and 3.5 respectively.

D.1.15 WCHANGE

The command WCHANGE should be issued when either a new WYFFOS filter or new WYFFOS grating has been loaded. The command proceeds by a series of prompts to the user.

The initial menu displayed when the WCHANGE command is issued is as follows :

```
ICL$>$ wchange
*********\wyffos Items which may be changed. *************
********** Input option required. 0 to exit **************
 0 - Exit this Procedure
 1 -\wyffos Filter
 2 -\wyffos Grating
 3 - Update Grating Offset Angle
Option? [0]
```

Depending on whether grating or filter is being changed, a number should be entered: Enter 1 for a filter change, 2 for a grating change or 0 (default) to exit from the WCHANGE command.

D.1.15.1 Grating

This command is issued when the WYFFOS grating has been changed. Option 2 should be selected from the initial WCHANGE menu. The menu for grating change proceeds as follows (note that the grating list shown is for illustrative purposes only)

```
Option? [0] 2}

Currently available \wyffos gratings are:
Grating Name   Ruling (lines/mm)
    R158R            158
    R316R            316
    R600R            600
   R1200R           1200
(Total of 4 \wyffos gratings available)

Current grating is R158R. Ruling =  158 lines per mm.
Enter new \wyffos Grating name (Default : R158R) >
```

Enter the new grating name : it must be a name shown in the displayed list. The name and ruling density of the specified grating will then be displayed by way of confirmation.

If there has been no actual grating name change, just hit <return> : the current grating information will be retained. If an unknown grating name is given this is ignored.

D.1.15.2 Barcoded Filters

The following example illustrates the use of the WCHANGE command when filter barcodes are in use.

```
Option? [0] 1

Currently available \wyffos filters are:
```

```
 Filter Name   Filter Thickness (mm)
   GG495            1.013
   OG570            1.013
   RG630            1.013
   BG39             1.013
(Total of 4\wyffos filters available)
```

```
Hit <Return> if the filter in\wyffos filter slide A or B has been changed
Type 'E' if there has been no change and you want to exit now.
```

Both filter slides will then be moved to the OUT position - this is necessary to be able to read the barcodes. The barcode values are then read and the filter names retrieved from the barcode database file. Messages of the following format should be seen on the terminal:

```
Reading barcodes...Moving filters A and B to the OUT position...

WYFFOS filter in slide A has barcode value 95. Filter name = RG630
WYFFOS filter in slide B has barcode value 96. Filter name = GG495
```

The corresponding focus adjustments for each filter are retrieved and stored.

D.1.15.3 Non-Barcoded Filters

If filter barcodes are not fitted or inoperable then the command WBARCODES should be issued to ensure that manual filter name input can be done. Issue the command :

ICL> WBARCODES NO

to disable filter barcode reading. Instead of reading the filter barcodes, the WCHANGE command (option 1) will instead prompt for the filter A and B names in a similar manner to that illustrated for the grating name shown above.

D.1.16 Software Failure Recovery

WYFFOS commands are available which can be used when the WYFFOS software appears to have hung or crashed and a full restart of the system is being avoided.

D.1.16.1 Quick recovery

The following sequence of ICL commands enables a rapid restart of WYFFOS software in the event of the WYFFOS control software hanging or behaving incorrectly:

```
ICL> KILL WYFFOS
```
(Kill the WYFFOS control task)
```
ICL> TASKS
```
(List the current tasks, ensuring WYFFOS is absent)
```
ICL> WYFFOS_LOAD
```
(Re-loadWYFFOS control task)
```
ICL> WYFFOS_BEGIN
```
(InitialiseWYFFOS system)
```
ICL>
```

D.1.16.2 Restart WYFFOS Procedures

The following commands are automatically issued at system startup time. They can also be used directly from ICL when a WYFFOS software reload is necessary due to the system failing or hanging. When used, the commands should be issued in the order listed:

WYFFOS_DEFINE :	This defines allWYFFOS commands. (It should never be necessary to re-issue this command during an ICL session).
WYFFOS_LOAD :	this loads the WYFFOS control task. To be used if the WYFFOS control task has crashed.
WYFFOS_BEGIN :	this starts the control task and performs various WYFFOS initialisations. This command should be issued following WYFFOS_LOAD.

Appendix E

Pre-observation: fibre configuration

E.1 AF2_CONFIGURE

E.2 Introduction

In this document we describe the use of the program **af2_configure**, which is designed to create the mapping between the objects that will be observed during a particular **wyffos** exposure and the fibres that will observe them. In its most general mode it will take an input file with the coordinates (α, δ) of the objects, create a fibre to object mapping using one of two currently available placement algorithms, and then allow the user to edit the placement interactively. Three files are required for input to the program: a fibre information file, a telescope information file and an object field file. In general only the last of these will be required of the user. In section E.3 we describe all three of these files and give an accounting of the required information for the input object field file. During a run the user will be prompted for some information, which will be explained in Section E.4. A sample run is also included. Section E.5 explains how to use the interactive editor and describes each of the available editing options. The available placement algorithms are described in section E.6. If you have a done a configuration on a field and you would like a hard copy of that configuration without having to go back into **af2_configure**, then the application **af2_hcopy** is available and is described in Section E.7. Section E.8 gives instructions on how to obtain and install the package. Finally, in the appendices we list some common errors and some programming notes.

E.3 The input files

E.3.1 The fibre information file

One thing which is common to all AF2 bundles is that there are two basic type of fibres, program or fiducial. The former are used for the program objects and the latter for fiducial or guide objects. Both of these types of fibres will be assigned a status according to one of these criteria:

missing The fibre is physically missing

disabled The fibre has been disabled for some reason (perhaps it is broken).

dead The fibre has very low transmission.

ok The fibre can be used for placement.

The fibre status will be decided by the micro which runs AF2 and the results will be put to the 'fibre information file'. This file also contains other information such as the park position of each fibre and their current x,y positions. The name of this file is constructed by adding the name of the bundle to the string '_fibres.dat'. Thus the fibre information file for the 'large' bundle will be called 'large_fibres.dat'. A copy of this file will be provided with the executable image of **af2_configure**. It may be the case however, that the installed version is rather out of date. In that situation it is possible to obtain a newer version and tell **af2_configure** how to find it. Section E.4 explains how to do this.

E.3.2 The telescope information file

The scale and distortion of the field of the telescope is stored in the telescope information file, called 'wht_prime.dat'. As with the fibre information file it is provided with **af2_configure**, but may well go out of date. If this is the case, a better version can be obtained and used. Again see Section E.4 to find out how this is done.

E.3.3 The input field file

In general the only input file required of the user will be the file which contains the coordinates of the objects to be observed. This we will call the *field* file from now on. The field file has two sections – the header and the object information. Comment lines may appear anywhere within the field file. These have an asterisk in the first column and will be ignored by **af2_configure**. The field file can be called anything you want, so long as it has the extension '.fld'. Note that **af2_configure** is *always* case sensitive in the specification of file names. Therefore the field file extension must be in lower case.

There are seven header items, all of which you *must* specify in each field file. (NB: The header items can appear in whatever order you wish, but they must *all* be there once and only once and they must appear in the field file *before* the first line of object information.) The header items are as follows:

centre The RA and DEC of the centre of the observation field. The hours and minutes columns of the RA and the degrees and minutes columns of the DEC should be expressed as integers. The seconds columns of both RA and DEC should be expressed as reals. Example:

CENTRE 12 34 15.3 -00 30 17.4

equinox The equinox of the coordinates. Note that the equinox of the field centre *must* be the same as that for the objects! Example:

EQUINOX 2000.0

utdate The date of the observation expressed as the year and a fraction. For example, if observations are being done on 30 June 1995, the value of **utdate** would be 1995.50. Example:

UTDATE 1995.89

ha The hour angle of the observation ($T - \alpha$, where T is the local sidereal time). This is vital in order to calculate the refraction correction properly. If a configuration is done with an hour angle which is vastly different from that which will be used at the telescope, **af2_configure** may not pick up collisions between fibres which might occur. This may mean wasted time at the telescope while another configuration file is created. If configurations are being done in advance, it may well be worthwhile doing several runs with different values of the hour angle and then at the telescope choosing the one appropriate for the time of observation. Example:

HA 0.5

target The name of the field. Each of your fields should have a unique name. This will be important at the data reduction stage. Example:

TARGET Field1 in SGP

skypa The position angle of the spectrograph on the sky. This should be expressed in degrees. It can sometimes be useful to change the value of **skypa** in order to get a better solution, especially with regard to fiducial objects. If **af2_configure** is used in angle scanning mode (see Section E.4), then this value will be ignored. Example:

SKYPA 90.0

fibres The name of the fibre bundle to be used in the observations. The only option which is currently available is 'LARGE'. Example:

FIBRES LARGE

All of the information for each object should all appear on a single line. See the sample field file below for examples. The data required for each object is:

name (Column number 1) This should be any alphanumeric string representation of the object name. Note that there should be **no** spaces embedded in the name! Perhaps use underscores instead.

ra (Column number 2–4) This is the RA of the object. The hours and minutes must be expressed as integers; the seconds should be expressed as a real.

dec (Column number 5-7) This is the DEC of the object. The degrees and minutes must be expressed as integers; the seconds should be expressed as real.

type (Column number 8) This is the object type and can take one of three values:

P – Program object

F – Fiducial object

S – Dedicated sky patch

Any other value will result in an error and the object will be ignored. Note that object types are *all* upper case.

weight (Column number 9) The user can weight the objects in order to increase the chance that a particular object will be allocated. The weighting can be according to any arbitrary scheme so long as the value is expressed as a real number which is greater than or equal to zero. Weights will be interpreted in the sense that a higher numerical value corresponds to a higher weight. Avoid weights of zero unless that is exactly what you mean.

magnitude (Column number 10) This is an estimate of the magnitude of the object in any band you wish and is only optional. The value is read as a real number.

anything else You can fill out the rest of the line with other information about the object. Make sure you prefix these comments with an asterisk. Otherwise **af2_configure** may think that the first word of your comments are in fact the object's magnitude! This information will for the most part be ignored by **af2_configure**, but it may provide some useful notes for you.

Below is a small example field file.

```
TARGET Example field file
UTDATE 1995.6
EQUINOX 1950.0
SKYPA 0.0
FIBRES LARGE
CENTRE 22 33 00.0 1 15 00.0
HA 1.0
S115 22 32 58.72 0 53 43.3 F 1 12.41 *
S2 22 31 49.84 1 44 54.3 F 1 12.46 *
S49 22 34 29.97 1 22 31.0 F 1 12.47 *
S10 22 33 15.48 1 40 30.1 F 1 12.50 *
S74 22 34 43.05 1 18 14.0 P 0.5 15.97 *
S52 22 32 38.00 1 22 56.9 P 0.5 15.98 *
S156 22 33 58.15 1 5 16.1 P 0.5 15.98 *
S151 22 33 28.17 1 6 11.9 P 1 16.01 * carbon star??
S103 22 32 8.10 1 14 38.8 P 1 16.05 *
S99 22 33 2.83 1 14 55.1 P 1 16.14 *
S207 22 31 24.14 0 50 58.7 S 1 *
S175 22 33 57.09 0 59 56.3 S 1 *
S122 22 32 27.50 1 12 17.0 S 1 *
```

E.4 Running AF2_CONFIGURE

E.4.1 Prompted information

If **af2_configure** has been installed at your site, then you should be able to access it by just typing '**af2_configure**' at the UNIX prompt. If this fails then contact your system manager. It may be that you need to put something in your default path in order to access the binaries.

As with most programs, **af2_configure** requires a certain amount of information from the user. In this section we give a listing of all of the prompts which you might encounter during a run. These will be roughly in the same order as they occur during a run. The values in parenthesis are the default values. Note that not all prompts will have defaults. If you wish to accept the default, then you can simply hit the carriage return button. (In what follows below, some prompts have parenthesis with nothing in them. This indicates an prompt which has a default which is decided at run time.) If you want to get out of **af2_configure** gracefully, you may type '!!' at any of the prompts and the program will abort. If you answer any of the questions in a way which **af2_configure** can't understand (e.g. you answer a yes/no question with a number) then you will be reprompted.

Define WHT_AF2DATA_DIR ( ) In **af2_configure** the fibre information file and the telescope information file are sought in a directory which is determined by the environment variable 'WHT_AF2DATA_DIR'. If you have set this, e.g.

```
% setenv WHT_AF2DATA_DIR /data/disk3/jrl/
```

then you will just be informed of its value. If you haven't set this up in advance, then this prompt will appear with the default being the directory where the binary for

af2_configure is located. In most cases you can just hit return and accept the default value. If you have new versions of the fibre information file and the telescope information file, then you'll need either to answer this prompt with the directory which holds these files, or define the directory before invoking **af2_configure**, as per above.

Do initial placement by scanning SKYPA? (no) **af2_configure** can be run in an angle scanning mode which allows you to sample a number of different values of the sky position angle (**skypa** in the field file) in order to try and get the best possible orientation.

Input field file This is the name of the field file – that is the file with the RA and DECs of the program objects described in section E.3.3. In specifying the file, it is not necessary to include the '.fld' file extension.

Do you want verbose output? (no) If you want some extra information as the program is running, you should answer 'yes' here.

Use old configuration file? (no) If you have done a configuration on this field before, then you may use the old configuration file as a starting point for this run. (For a discussion of configuration files, see section E.4.3.) This can be quite useful if you want to break off a run and pick it up again later. It can also be useful if you don't like a certain configuration and all you want to do is to edit it. Note that you cannot use an old configuration file in angle scanning mode.

Which version do you want to use ( ) If you have decided you want to use an old configuration file, you will be prompted for a version number. The default in the prompt will be the most recent version number. If you only have one old version, then you won't be asked this question.

How many position angles to try? (10) This is the maximum number of position angles to scan in angle scanning mode.

Which statistical measure to use? (2) While in angle scanning mode, **af2_configure** decides which is the best scan by either (1) seeing which scan results in the most objects allocated or (2) seeing which scan results in the highest total weight. (For uniformly weighted objects, these are obviously equivallent.)

Buffer factor for fibre dimensions (1.00) This is a factor by which the tube width and the button dimensions will be multiplied in order to increase their sizes artificially. This is quite useful if you are worried that possible fibre collisions will cause **af2_configure** to generate illegal configurations. For example, if the buffer factor is 1.05, then the fibre dimensions will be increased by 5%. The value can not be less than 1.0.

Which fibre placement algorithm? (2) This is the prompt you will get for the fibre placement algorithm when using **af2_configure** in its normal mode (not in angle scanning mode). See Section E.6 for a description of the available algorithms.

Which algorithm to use during the scanning? (1) This is the prompt you will get when in angle scanning mode for the algorithm to be used during the scanning.

Which algorithm to use for final placement? (2) This is the prompt you will get when in angle scanning mode for the algorithm to be used after the scanning when you have decided which is the best position angle.

Iterate the placement? (yes) Once the placement has been done either by using one of the placement algorithms, or by reading the initial placement from an old configuration file, then you may iterate the configuration in an attempt to increase both the number of objects placed and the total weight of the objects placed. This is usually helpful and is recommended.

Plot configuration and allow for editing? (yes) If you want to edit the configuration, or if you just want to have a look at it, then answer 'yes' here.

Show whole plate? (no) If you are going to plot the configuration you may display the entire fibre plate if you so wish. If the whole fibre plate is displayed it can make seeing the objects and the fibres a bit difficult. You do have the option under these circumstances to zoom, though. There aren't many reasons for wanting to see the whole plate, so if you answer 'no' here, the maximum view you will have is 1.1 times the park radius, which certainly makes for a better view.

Graphics device/type (? to see list, default /NULL) This is the prompt for a graphics device direct from PGPLOT. If you are not sure, then type '?' for a list of the available devices at your site. (/xw will usually get the xwindows server.)

Number of fiducials required for acquire ( ) This is the number of fiducials to put at the end of the output configuration file. This is for the use of the routine **af2_acquire**, which is run at the telescope. The default value will be the total number of fiducials which were read in from the field file. If you don't know or don't care, then just use the default.

Generate an x,y file? (no) Answering 'yes' here will cause a file with the extension '.fib' to be generated. In it will be the x,y positions of the fibres. This may be useful in comparing the results of this program with that of **af2_setup**.

Generate a new field file? (no) You have the option to create a new field file which will be exactly the same as the current one with two exceptions: (1) all of the objects which have been configured on this particular run will be zero weighted and (2) the field name will be altered slightly. The former is so that you can run a second configuration on the same field and you will preferentially allocate the objects which didn't get allocated the first time around. The latter ensures you don't have problems at the data reduction stage.

New field file name If you have opted to create a new field file as described in the previous item, then this is the name of the new field file. Omit the '.fld' extension. Also, make sure that it has a different name from the original field file. Otherwise the latter may get clobbered by the new file.

E.4.2 Sample runs of AF2_CONFIGURE

Below is a sample run of **af2_configure**in its ordinary mode. Some comments on the run:

1. The user has let the value of WHT_AF2DATA_DIR default to the location of the **af2_configure** binary. If new versions of wht_prime.dat and large_fibres.dat were available, then the user should request that WHT_AF2DATA_DIR be set to the directory where they are stored.

2. By answering 'no' here the user will be running **af2_configure** in its usual mode (*i.e.*not in angle scanning mode).

3. As is seen on the following line, the input file is called 'f891.fld'. Note that the user has omitted the file extension; typing the extension isn't necessary.

4. The user has opted for verbose output. Much of what you'll see following this line wouldn't be printed out if **af2_configure** were being used in a quiet mode. For the sake of brevity much of the repetitive information which the user would have received at the terminal during this run has been edited out.

5. The fact that the user was prompted for this means that there already exists at least one configuration for this field in the current working directory (the first such file would be called 'f891.cfg.1'). The fact that he has answered 'no' to this question means that a completely new configuration will be generated now. If he had answered 'yes', then a version number would have been prompted for and the program would have skipped to reference mark 7 and then to 10.

6. The program has read the field file. A number of the objects in the field file are outside the field radius and will be skipped. These are denoted here.

7. This is an accounting of the various types of objects which have been read in from the field file.

8. The user has decided to use the fibre dimensions as they have been read from the fibre information file. If there was a certain amount of paranoia about possible collisions causing illegal configurations, then a value of 1.05 would have been reasonable.

9. The SLOW algorithm will be used. As previously mentioned, this is the algorithm which tries to maximise the total sum of weights of the objects placed.

10. This is an accounting of how well the placement algorithm did. Note that no sky patches were placed. This is not necessarily a problem since there were no sky patches read in from the field file (see reference label 6).

11. The user has decided to iterate the initial placement. As can be seen from the progress report it has resulted in the allocation of more objects and an increase in the sum of the weights.

12. Both placement algorithms will initially ignore objects with a zero weight. If there are any fibres left over after the initial placement, then **af2_configure** allows the 'old' algorithm to try and place these spare fibres on objects which have a zero weight (*i.e.* something is better than nothing). In this instance, no extra fibres were placed.

13. The user has opted to edit the placement. The maximum radius of the display will be a little greater than the park radius and the PGPLOT device will be '`/xw`', which is an X-windows device. If you are not sure what to type here, you can type '?' for a list of available devices on your system.

14. After editing the user has opted to add 10 fiducial objects to the output configure file for the use of **af2_acquire**.

15. The user has decided not to write out a file with the x,y coordinates of the fibres, nor will a new field file be written out.

```
Define WHT_AF2DATA_DIR (/home/jrl/disfigure/dev) >                     (1)
Taking standard telescope and fibre info from: /home/jrl/disfigure/dev
```

```
Do initial placement by scanning SKYPA? (no) > no                      (2)
Input field file > f891                                                (3)
Input field file is: f891.fld
Do you want verbose output? (no) > yes                                 (4)
Use an old configuration file? (no) > no                               (5)

Reading through field data file f891.fld


Field label is F891 GALAXY FIELD
UT date of observation is 1995.6
Equinox is 1950.0
Sky PA is 0
Fibre bundle is LARGE
Field centre is 22 33 00 1 15 00
Hour angle is 0



Reading in object data
Object outside field radius  104608.22  -33698.21                      (6)
Object outside field radius   78577.63 -105197.33
Object outside field radius   96937.29   89367.50
Object outside field radius   61893.86  105188.60
Object outside field radius  -24283.27  104391.30
Object outside field radius  -91821.71   95333.59
Object outside field radius   84109.77  -84574.93
Object outside field radius   74866.70   73593.21
.
.    (lines edited out)
.
Object outside field radius  -86203.52   77466.41
Object outside field radius   80513.41   87847.52
Object outside field radius   46928.51 -100869.52

 21 fiducial objects                                                   (7)
162 program objects
  0 sky positions
 38 objects outside of field

Buffer factor for fibre dimensions (1.00) >                            (8)
Trying to configure 183 objects and 136 pivots

Which fibre placement algorithm?
(1) The FAST algorithm
(2) The SLOW algorithm
Choose one (2) >                                                       (9)
Looking for all possible object-fibre combinations...
   860 possible object-fibre combinations found
Now calculating badness index for each combination
Sorting by badness
```

```
Placing the fibres now...
putting fibre 125 on object  33 S34
putting fibre  20 on object 110 S77
putting fibre  26 on object  59 S58
putting fibre  29 on object  82 S56
putting fibre  44 on object  43 S122
putting fibre  12 on object 102 S73
putting fibre 126 on object 123 S96
putting fibre  18 on object 116 S39
putting fibre  11 on object 118 S13
putting fibre  37 on object  66 S111
putting fibre  39 on object 124 S129
putting fibre 128 on object 130 S25
putting fibre 121 on object 120 S20
putting fibre 119 on object  61 S28
putting fibre  99 on object 111 S115
.
.           (lines edited out)
.
putting fibre 115 on object 148 S60
putting fibre  85 on object 173 S201
Looking for all possible object-fibre combinations...
     2 possible object-fibre combinations found
Now calculating badness index for each combination
Sorting by badness
Placing the fibres now...
putting fibre  40 on object 104 S139
Looking for all possible object-fibre combinations...
     0 possible object-fibre combinations found

Total number of objects allocated:  86                               (10)
Total sum of weights of allocated objects:   75.5
Total number of sky patches allocated:   0

 80 program objects placed
  6 fiducial objects placed
  0 sky fibres placed
  0 placed by cursor only
Iterate the placement? (yes) > yes                                   (11)
Current sum of weights   75.5
Iteration:   1, number of attempted changes:  7
   Sum of weights now:   79.0
Iteration:   2, number of attempted changes:  0
   Sum of weights now:   79.0
Final sum of weights is:   79.0
 88 program objects placed
  5 fiducial objects placed
  0 sky fibres placed
  0 placed by cursor only
```

```
Trying to place spare fibres on objects with weight <= 0.0            (12)
 88 program objects placed
  5 fiducial objects placed
  0 sky fibres placed
  0 placed by cursor only
Plot configuration to allow for editing? (yes) > yes                  (13)
Show whole plate? (no) > no
 Graphics device/type (? to see list, default /NULL): /xw
.
.     (fibre plot is displayed and the user edits the configuration)
.
Number of fiducials required for acquire? (21) > 10                   (14)
 88 program objects placed
  5 fiducial objects placed
  0 sky fibres placed
  0 placed by cursor only
Generate an (x,y) file? (no) > no                                     (15)
Generate a new field file? (no) > no
```

Here is another sample run. This is **af2_configure** in angle scanning mode. The comments below refer to items which differ from the previous run.

1. The user has opted to use angle scanning mode
2. There will be four scans (*i.e.*at position angles 0, 90, 180 and 270).
3. The best scan will be judged to be the one which maximises the sum of the weights of the objects allocated.
4. During the scanning of the four position angles, the initial placement will be done by the FAST algorithm.
5. Once it has been decided which is the best position angle, the the SLOW algorithm will be used to do the final placement.
6. These are the running results for each scan.
7. The best result was achieved with a position angle of 0.
8. This is the result of using the SLOW algorithm for the final placement at position angle 0 degrees.
9. The user has opted to iterate the placement as before. The rest of the run is exactly the same as running **af2_configure** in normal mode.

```
Define WHT_AF2DATA_DIR (/home/jrl/disfigure/dev) >
Taking standard telescope and fibre info from: /home/jrl/disfigure/dev
Do initial placement by scanning SKYPA? (no) > yes                    (1)
Input field file > f891
Input field file is: f891.fld
Do you want verbose output? (no) >
```

```
How many position angles to try? (10) > 4                              (2)

Which statistical measure to use?
(1) The total number of fibres placed
(2) The total weight of the fibres placed
Choose one (2) >                                                        (3)

Which algorithm to use during the scanning
(1) The FAST algorithm
(2) The SLOW algorithm
Choose one (1) >                                                        (4)

Which algorithm to use for final placement
(1) The FAST algorithm
(2) The SLOW algorithm
Choose one (2) >                                                        (5)
Buffer factor for fibre dimensions (1.00) >

Field label is F891 GALAXY FIELD
UT date of observation is 1995.6
Equinox is 1950.0
Sky PA is     0.00
Fibre bundle is LARGE
Field centre is 22 33 00 1 15 00
Hour angle is 0


Results for scan:  1, position angle:    0.00                          (6)
Total number of objects allocated:  91
Total sum of weights of allocated objects:   71.0
Total number of sky patches allocated:   0


Results for scan:  2, position angle:   90.00
Total number of objects allocated:  88
Total sum of weights of allocated objects:   65.5
Total number of sky patches allocated:   0


Results for scan:  3, position angle:  180.00
Total number of objects allocated:  92
Total sum of weights of allocated objects:   70.2
Total number of sky patches allocated:   0


Results for scan:  4, position angle:  270.00
Total number of objects allocated:  90
Total sum of weights of allocated objects:   70.5
Total number of sky patches allocated:   0
```

```
Best result was:   71.00 for position angle    0.00                     (7)

Final result for position angle:    0.00                                (8)
Total number of objects allocated:  92
Total sum of weights of allocated objects:   83.2
Total number of sky patches allocated:   0

Iterate the placement? (yes) >                                          (9)
Current sum of weights   83.2
Final sum of weights is:   86.0

Trying to place spare fibres on objects with weight <= 0.0
 90 program objects placed
  6 fiducial objects placed
  0 sky fibres placed
  0 placed by cursor only
Plot configuration to allow for editing? (yes) > no
Number of fiducials required for acquire? (21) > 10
 90 program objects placed
  6 fiducial objects placed
  0 sky fibres placed
  0 placed by cursor only
Generate an (x,y) file? (no) >
Generate a new field file? (no) >
```

E.4.3 Output files

The output from **af2_configure** will be some or all of the following files:

Configuration file This is the main output file and so long as the program completes successfully you will always get one. It is used at the telescope as input to **af2_setup** which is ultimately responsible for moving the fibres to the correct positions. This file will be called by the same root name as the input field file, but with the extension '.cfg' and a version number added. For example if the input field file were called 'm51.fld', the first output configuration file would be called 'm51.cfg.1'. The contents of the configuration file start with a listing of the telescope information file contents. This was done so that there would be no doubt as to which version of the telescope information file was used for any given configuration. The next seven lines are the header from the field file. After the header is a line for each fibre. The first column is the fibre number. This is followed by the information (name, α, δ, *etc.*) on the object to which that fibre has been allocated. Fibres which have not been allocated have a one word description for the reason they are so, e.g. 'PARKED' or 'DISABLED'. Fibres which have been placed by cursor positions in the editor will have an object name 'PLACE_XY'. Following that will be the α and δ which **af2_configure** has calculated for the location and the original x,y coordinates. Note that the x,y coordinates for objects are *not* included as they will be recalculated by **af2_setup** at the telescope. That program will also recheck the configuration for fibre collisions. At the end of the configuration file is a list of fiducial objects which can be used by the program **af2_acquire** for locating and centring the region. These objects all have fibre numbers greater than 900 and are ignored by **af2_setup**. Editing this file is *strongly* discouraged.

Log file This is a log of the information read from the field file plus any comments which **af2_configure** may have about it. As with the configuration file above it will have be same root name as the input field name, but with the extension '.log' and a version number. Thus for an input field file called 'm51.fld' the first log file will be called 'm51.log.1'. This file may be useful for you if **af2_configure** has signalled an error in your input file (fatal or not). This may include files falling outside of the field radius or errors in the format of the input file. It is not used as input for any other program so you are free to do with it whatever you like.

x,y file This is an optional file which will be generated if the user requests it as in item 14 in the first example of the previous section. As with the previous output files, it will be called by the same root name as the input field file, but with the extension '.fib' and a version number. The first four lines of the file will be header information. Each of the following lines will have a fibre number followed by the x,y coordinates assigned to that fibre by **af2_configure**, irrespective of whether the fibre has been allocated or not.

Revised field file When running **af2_configure** in angle scanning mode you will almost inevitably create a configuration with a sky position angle which is different from that in the input field file. For that reason, **af2_configure** will silently rename the original field file (by appending the suffix **OLD** to the basename) and create a revised field file which is in every way the same as the original with the exception of the value of **SKYPA**. This will then allow you to use **af2_configure** a second time in normal mode in the event that all you want to do is to edit the configuration. (Remember, the header of the field file and the header of the configuration file *must* match if you are using an old configuration file). You only get this revised field file on angle scanning mode!

New field file This is also an output file which is generated by request. The answer which the user gives should be the root name of the new file. The extension '.fld' will be appended automatically. Note that version numbers are not supported for field files. The contents of the file will be almost the same as that of the input field file except that the NAME in the header will be slightly different (to avoid complications at the data reduction stage, all field should have a unique name), and all of the objects which were allocated on this particular run will have a weight of zero.

Any PGPLOT hardcopy files You'll get these if you request hard copies during an editing session. The file names will depend on the format you request. Default names are hard-coded into PGPLOT. Note that it is possible to request a file name at the same time you are requesting the device type. For example when PGPLOT requests a hard copy device, you could just answer: '/ps' which will give you an output postscript file called 'pgplot.ps'. If you would rather have an output file called 'george.ps' then you can do so by answering 'george.ps/ps' to the PGPLOT hard device prompt.

E.5 Editing a configuration

At some stage during a configuration you will probably want to see and/or edit the placement. This is done in the interactive editor which appears if you request it in step 12 of the first example in the previous section. For various reasons it is recommended that you use a device with some sort of colour capabilities like a colour graphics X-terminal or Sun workstation.

When the plot is first displayed you should see markers denoting the locations of all of your objects and drawings of each of the fibre tubes and buttons. Tables E.1 and E.2 explain the colour coding for each.

Table E.1: Colour scheme for objects

Object type	**Marker type**	**Marker colour**
program	plus sign	red
sky patch	open circle	magenta
fiducial	asterisk	light blue

Table E.2: Colour scheme for fibres

Fibre type	**Colour**
good program	green
good fiducial	blue
disabled program	red
disabled fiducial	magenta
dead program	red+magenta
dead fiducial	blue+magenta

In Table E.3 we give a listing of the available edit options in alphabetic order. In what follows we group these options into like actions and give a full description of each. Note that although these options appear in the table all in upper case, the editing commands are not in fact case dependent.

E.5.1 Getting information

The following options are useful for getting information about fibres, objects and the configuration itself. The information will appear in the message window of the plot.

This gives exactly the same information is the **F** command below. The only difference is that after typing the '#' keystroke, the number of the fibre for which information is sought needs to be typed and followed by a carriage return. This therefore allows the user to get information about a given fibre without the need to know exactly where it is on the plot

F Information about the fibre whose button head is closest to the current cursor position is displayed. This includes the fibre number, its type and its current allocation state. The latter includes information on the object the fibre may be covering.

I This gives information about the object which is nearest the current cursor position. This includes a fibre number if this particular object has been allocated.

S The user will receive report of the status of the current allocation. That includes an itemised list of the number of objects covered (separated according to object type) and the sum of the weights of the allocated objects.

Table E.3: Available editing options

Option	Action
#	Type fibre no. and get information on it
A	Undo the most recent undo action
C	Move indicated fibre to cursor location
E	Exit from the editor
F	Get information on the indicated fibre
H	Make a hard copy of the current plot
I	Get information on the indicated object
M	Move the indicated fibre to an object
O	Zoom the plot outwards
P	Park the indicated fibre
R	Refresh the plot
S	Give a status report on the placement
U	Undo the most recent action
X	Zoom the plot outwards to the allowed maximum
Y	Restart the editing session
Z	Zoom the plot inwards

E.5.2 Moving a fibre

The following options allow the user to move a fibre in one way or another. Note that you will not be allowed to move a disabled or dead fibre, nor are you allowed to move a fibre outside of the park circle. In all of these there are certain rules which may prevent you from moving a fibre the way that you would like (e.g. no two fibres should cross or touch). If you are forbidden from moving a fibre in a particular way, the reason should appear in red in the message box.

C This is a two-keystroke operation. Pointing the cursor at a fibre head and typing **C** will cause the fibre to be highlighted. Then pointing the cursor at a desired location will cause the highlighted fibre to be moved to that location. Note the second keystroke needn't be a '**C**'.

M This is also a two-keystroke operation. Pointing the cursor at a fibre head and typing **M** will cause the fibre to be highlighted. Then pointing the cursor at an object will cause the highlighted fibre to be moved to that object. The second keystroke needn't be an '**M**'.

P This causes the fibre whose button head is nearest to the current cursor position to be parked.

E.5.3 Zooming in or out

The following options allow you to change the scale of the current plot (*i.e.* zoom). You cannot zoom out any further than the maximum radius. If you have opted to show the whole plate, then the maximum radius is the pivot distance. If you have not opted to show the whole plate, then the maximum radius is approximately 1.1 times the park radius. Note that for the **Z** and **O** options, the expansion or contraction of the field is done with respect to the location of the cursor. Thus you will be forbidden from user either of these commands with the cursor pointed somewhere outside the plot window,

O Zoom outwards by a factor of 2 in each direction.

X Zoom outwards to the maximum size allowed.

Z Zoom inwards by a factor of 2 in each direction.

E.5.4 Undoing your actions

af2_configure keeps a buffer with the most recent editing actions which you have performed during the current editing session. It is therefore possible to reverse some of your editing decisions. There is a limit to the size of the buffer which stores the editing history (currently 40 actions, but that can be changed by the person who builds the program) so you may not be able to backtrack as far as you would like. Note that once you leave the editor, all knowledge of the editing session is lost and you will not be able to undo your actions with these keystrokes during another run of **af2_configure**.

A If you have undone an action (keystroke **U**) and you are sorry you did so, then you can recover the situation by 'undoing the undo'. This option can only be used after having used the **U** option at least once and can be used to undo a whole series of **U** actions.

U Undo the most recent action.

Y If you are unhappy with your entire editing session, this option allows you to restore the configuration to the state it was before you started editing.

E.5.5 Other options

Here are some options which don't seem to fit into any of the other categories.

E Exit from the editor.

H Create a hard copy of the current plot. You will be asked for a PGPLOT hardcopy device (again you can type '?' for a listing of available devices). Once the file has been written, the plot will be redrawn on your screen.

R **af2_configure** attempts to redraw objects which would otherwise be erased when fibres are moved. Sometimes bits of object markers don't get redrawn and the park circle gets partially erased. You can use this option to refresh the plot and redraw anything which may be missing.

E.6 The placement algorithms

In this section we give a description of the two placement algorithms which are currently available in **af2_configure**. We also try to stress the benefits and the weaknesses of each method. In the original version of **af2_configure** and this document we referred to these algorithms as the 'old' and the 'new' algorithms. This wasn't very helpful. So in this version we have renamed them as the FAST and the SLOW algorithms. (This is slightly more informative but doesn't gain much in terms of imagination – sorry.)

E.6.1 The FAST algorithm

The FAST algorithm works on the principle of trying to place a fibre on an object in such a way that the placed fibre blocks as small an area of the rest of the field as possible, thus leaving a larger area of the field available for other fibres. This is done by starting with the last usable fibre in the bundle (in the numerical sense) – this should appear on the top of the fibre plot in the editing mode. The program works out which object can be reached by that fibre and will cause the fibre to extend to the maximum angular distance (as measured from its park position) in the anti-clockwise sense, without exceeding a preset limit imposed in the fibre information file. Again, we are restricted by various rules which don't allow fibres to cross or touch. Once a fibre has been considered (and placed on an object, if possible) the next fibre to be examined is a quarter of the way around the pivot circle. We keep jumping around the circle in quarters until all fibres have at least been considered.

The major advantage of this method is its speed. Even fields which are strongly clustered are dealt with very rapidly. Its main disadvantage is that it takes no account of the weight placed on the object (with the exception that it ignores objects with a zero weight). This means that although you may place a large number of objects, they may not necessarily be the ones you most want.

E.6.2 The SLOW algorithm

The SLOW algorithm attempts to maximise both the total number of fibres placed and the sum of the weight of the allocated objects. It does this by first finding all of the possible fibre-object combinations which don't break any of the placement rules. It then looks at each combination one by one and assess how many other combinations this particular one will block. A penalty function for the combination is computed based on the number of blockages, the weight of each object blocked and the weight of the object in the combination. Thus the penalty function tries to balance the blockage of some objects with the need to allocate the current object. Once the penalty function has been computed for each combination, the combinations are sorted by the value of their penalty functions. The algorithm then chooses the best combinations to place first.

The principal advantage of this method over the FAST algorithm is that it usually results in both a larger number of objects allocated as well as a higher sum of weights. For this reason, this is the preferred option for most fields. The disadvantage of this method can be its speed. For a reasonably well dispersed field (where each object may be reachable by 5 or 6 fibres) the algorithm takes about a minute on an unloaded Sun Classic workstation. This can get prohibitively long for fields with large numbers of objects which are centrally concentrated (say a globular cluster) where the number of fibres which can reach each object without breaking the placement rules gets to be very large (say 20 or so).

E.7 Getting hard copies using af2_hcopy

If you have a configuration and you would like to obtain a hard copy of it, you could get into **af2_configure** by using this configuration as an old configuration file and then creating the hard copy in the editor. If you don't want to go through all that, then **af2_hcopy** is a convenient shortcut. This program simply reads the old configuration file, the fibre information file and telescope information file and creates a hard copy plot file of the configuration as you would see it in the **af2_configure** editor. The questions it asks are all included in Section E.4 in the list of prompts. The only thing to watch out for here is that you make sure that the PGPLOT device you specify is in fact a hardcopy device. If you specify a soft device, then an error will be signaled and the program will exit.

E.8 Installing AF2_CONFIGURE

The **af2_configure** package can be obtained either from the author or by anonymous ftp to the RGO (ftp.ast.cam.ac.uk). In the latter case the tar file can be found in the directory /pub/jrl/config, along with this document. The tar file contains all of the source code to **af2_configure** and recent versions of the fibre and telescope information files. **af2_configure** needs three main libraries before it can be linked. The first is Pat Wallace's astrometric library, slalib. If you are installing this at a STARLINK site, then you probably already have this available. If not, then a recent version of the library is provided in the **af2_configure** distribution. The same goes for the second library, which is the STARLINK 'chr' library. This is a suite of character handling routines of which **af2_configure** makes a lot of use. The third pre-requisite is PGPLOT which needs to be at either version 5.0 or above. There is a version of PGPLOT available at all STARLINK sites. Even so, the preferred option is to use the standalone version of PGPLOT which will plot *much* more quickly. This is available from Tim Pearson at Caltech through anonymous ftp (astro.caltech.edu or 131.215.240.1).

At present **af2_configure** has been tested on Suns running Sun/OS v4.1.3 or Solaris v5.4. It has also been tested on an ALPHA workstation running OSF1 v3.2.

Assuming that the **af2_configure** tar file has been brought over to your home institution it can be installed in the following manner:

1. Make a directory somewhere to hold the **af2_configure** directory tree and put the compressed tar file into it. Then issue the command:

   ```
   % zcat af2_configure.tar.Z | tar xpvf -
   ```

2. Type `% cd src` and get a listing of the directory. You should see a file called 'build'. Typing `% build` should cause the package to begin building.

3. The first thing that 'build' attempts to do is to locate a version of PGPLOT by looking at your environment variable `LD_LIBRARY_PATH`. If you don't have `LD _LIBRARY_PATH` defined, then it will search a couple of reasonably obvious locations (**/usr/local/lib** and **/usr/lib**). If it finds the PGPLOT library then it asks you if you want to use this version. If you do, then it proceeds to the next step. If not, it will search for a version in the STARLINK area. If it can neither use a standalone version nor find a STARLINK version, the build script bombs out.

4. The next question 'build' asks is whether or not you want to use the internal versions of 'chr' and 'slalib'. As we noted previously, the **af2_configure** package contains a recent release of the 'chr' and 'slalib' routines. If you answer 'yes' then these two internal libraries will be built. If you answer 'no' then it will search for these libraries in the STARLINK library area.

5. Finally, the **af2_configure** programs and scripts are built and installed. You should find three startup scripts, three binaries and some data files in the binary directory.

Once **af2_configure** has been built it can be accessed by putting the full path to the binary directory into the user's path (defined in the users .tcshrc file). Alternatively you could create soft links to the binaries and the scripts into a reasonably standard locations, e.g. **/usr/local/bin**.

E.9 Common errors

I have listed here some of the most common errors which you may encounter when running **af2_configure**. They are listed below by the message they generate. There are other error messages which you might encounter. Ones with the words 'programming error' at the end probably mean just that and need to be referred to the author.

Error opening file: <filename> The file which you have tried to open doesn't appear to exist in the current directory. Are you sure the file has the correct extension (.fld for a field file)? This error may also occur when trying to open a new file. In that case, are you sure you haven't run out of disc space?

The file <file> does not exist. Do you have the correct bundle in field file? The fibre information file name is formed by appending the fibre bundle name to the string '_fibres.dat'. Thus if you don't have the correct fibre bundle name in the header of your field file, then the file that **af2_configure** tries to open will either be wrong or won't exist. The other possibility is that in the definition of WHT_AF2DATA_DIR you have given a directory where the fibre information file you want doesn't exist.

Requested PGPLOT device is not a soft device! This may occur if you specify a hard device (e.g. a postscript file) when the PGPLOT device is first requested for edit mode. If you want a hard copy, you should first display the configuration on a soft device and use the **h** command in the edit mode to create a hard copy. You could also use **af2_hcopy** if all you want is a hard copy.

Input field file has no object data! Are you sure there is any object information in your field file after the header?

Maximum version number exceeded for <filename> There is a maximum version number for configuration files, log files and x,y files. This is preset in **af2_configure** but may be changed by whoever builds the package. If you get this error message, try deleting the old versions of the offending file and try again.

Error reading line <lineno.> of <filename> An error has occured in reading from a file which is supposed to be in a set format. Check the offending line in the file. This is not always regarded as a fatal error.

Too many fibres specified in <filename> The maximum number of fibres which **af2_configure** will accommodate is preset, but can be changed by whoever builds the package. If you get this error, then check the number of fibres as specified in your fibre information file.

Error reading <headeritem> in <filename> The header items must be specified in the correct format (e.g. UTDATE must be a number and not a character string). Check the offending header item in the specified file and see if it makes sense.

<headeritem> is multiply defined in file <filename> A header item must only appear once in a file.

<headeritem> is undefined in file <filename> All header items must be defined. See if the offending header item exists in the specified file. Also check that it is written *before* any object information.

<headeritem> in old config file doesn't match that of field file If you are using an old configuration file as the starting point for your current run, you must have the same values for *all* your header items in both the old configuration file and the current field file. This is to ensure that a valid configuration which exists in an old configuration file isn't made invalid by different header values in the current field file.

Collision detected between fibres <fibno.> and <fibno.> This is a serious problem that may occur when reading an old configuration file. Presumably the old configuration file has a legal configuration, so if we detect a collision when reading it back in, it may indicate that someone has edited the file. It may also mean that the original configuration was done with a smaller buffer size than you have entered in your current run.

E.10 Some programming notes

The current version of **af2_configure** is a very thorough revision/rewrite of a program of the same name by T.N. Wilkins at Durham (which was in turn based on a program written by I.R. Parry). I wish to stress that although almost all of the source code in this version is attributed solely to the author (done in most cases for simplicity), some of it is in fact based on the work of others, particularly in the design of the graphical routines.

This version will only work on UNIX-type platforms. There are several locations within **af2_configure** and its subroutines where searches are done for directories and these are only sought in a way which is consistent with UNIX path names. This could change in the future if there is sufficient demand.

Most of **af2_configure** is written in FORTRAN. In doing so, the author has tried to stay within the bounds of ANSI FORTRAN 77, but inevitably a few non-standard features have crept in. The main offenders are:

include: Include files are used extensively in **af2_configure** in order to define global parameters.

implicit none: This was used in order to make sure that all variables were declared.

do while: Used for the usual reasons.

%val: Used to pass pointers to workspace in subroutine calls.

long variable names: ANSI FORTRAN 77 specifies a maximum of 6 characters for the length of a variable name. This rule is broken fairly comprehensively in **af2_configure**.

$ format descriptor: This is used to suppress carriage control in the routine which prompts for values from the user (getval.f).

A small subset of routines have been written in ANSI C. These all have the prefix 'csub_' to their names and are used for operations which FORTRAN 77 can't do (e.g. allocating dynamic memory).

For the most part **af2_configure** is independent of the telescope and should be reasonably easily changed if a person wants to use it for a different fibre positioner or telescope. The following may need to be changed if **af2_configure** is to applied to another system:

af2_par.inc, af2_par.h These are include files for the FORTRAN and C routines respectively. If one is changed you must be careful to change the other as well. The parameters in these files define the maximum number of objects, the maximum number of fibres and many other purely internal parameters, which may never need changing.

af2_obs.inc This is an include file which is used by the astrometry routines. The parameters define various aspects of the observatory and telescope. The quantities are all documented in the file comments.

af2_fsta.inc This is an include file which defines the values of the fibre status variable (e.g. whether the fibre is good, broken, object, fiducial or whatever) for each type of fibre. **af2_configure** inherited these definitions from the AF2 micro software and the fibre information file has the fibre status defined in terms of these values.

platexy.f, centrexy.f, xytord.f These are the three main astrometric routines. For the most part these should be the same for all telescopes. What may need changing is the definition of the rotator angle and the direction cardinal axes of the instrument. These sections are commented in the code.

Information on object and fibre positions is carried around in two types of data what I call here 'static' and 'variable'. The static data have information which never changes after they have been read in from the input files. The variable objects are changed and rearranged during the course of the fibre placement. These data are called almost without exception by the same variable names in all routines in **af2_configure**. A list of the main static information regarding the objects is given below:

nobj, nsky These are the number of objects and the number of sky patches which were read in from the field file. Note that all fiducial objects are included in **nobj** and that both will exclude objects/skies which fall outside the field. Integers.

object, skypos These are arrays of the x,y coordinates of the objects and sky patches respectively. They will have been derived from the (α, δ) included in the input field file. Real arrays

otype This is an object type for the **object** array and is used to differentiate between program and fiducial objects. The values are set to either 'fsta_ook' or 'fsta_fok', as defined in the file 'af2_fsta.inc'. Integer array.

plog, slog These are arrays which carry around almost the whole of the input field file. Each element is an 80 character string which contains the input line from the field file for a particular object (program or fiducial) or sky patch. I quite often refer to these as the 'object information log' in the comments. Character arrays.

weight, sweight These are the arrays which carry around the defined weights for the objects and sky patches respectively. Real arrays.

The important static information regarding the fibres is:

fibstatus This is an array of values which describe the fibre's status. By 'status' we mean its availability for use, e.g. if the fibre is broken then it is flagged as such. The values it can have are described in the include file 'af2_fsta.inc'.

piv This is the array of x,y positions for each of the fibre pivots. Integer array.

park This is the array of park positions for each of the fibres. Integer array.

The variable information is what essentially describes the configuration. This is covered in the list below:

object_ref, sky_ref These are referred to repeatedly in the code as the object reference list and the sky reference list. They contain a list of objects/skies which have not yet been covered by a fibre in the current configuration. For various reasons these arrays may be rearranged and it is important to realise that the value in a reference list refers to a particular object/sky in the static information. For example, if the object reference list has been sorted in such a way that the first item in the list is the one which would best suit a particular fibre. Then if **object_ref(1)** equals 30, this means that the object whose x,y coordinates are in **object(1,30)** and **object(2,30)** and whose weight is stored in **weight(30)**, and so on is the one that is best suited for the fibre in question. Integer arrays.

n_obj_left, n_sky_left These are the number of object and sky patches respectively which have not yet been covered by a fibre. Another way of looking at this is that they are the number of objects still available in the object and sky reference lists. Integers

fib This is the current x,y coordinates of each of the fibres (in microns from the centre of the field). Integer arrays.

allocated Initially all of the elements of this array are give a value of zero. This is to indicate that the fibre is available to be used for an object. If the fibre is disabled, dead or missing, then the element of this array corresponding to that fibre is given a value of -10, -20 or -30 respectively. Any fibre with a negative value in this array is automatically ignored for configuration and editing purposes. If the fibre is later allocated to a particular object, then the value of this array for that fibre is changed to the reference list number of the object in question. If the fibre is allocated to a sky patch then the appropriate element of this array is set to the reference list number of the sky patch, plus a standard offset value which is called **alloc_sky** internally. If the fibre is allocated to a cursor location in the editor, then the value of this array is set at a single standard value, called **alloc_cur**. Both of these standard values are set in the include file 'af2_par.inc'. It is quite often the case that a routine in this package will use the value of this array to determine what type of object is being covered. Take, for example a value of *ix* for a particular element of this array. If *ix* equals **alloc_cur** then we know the fibre was placed on a cursor location in the editor. If its value is greater than **alloc_sky**, then we know its placed on the sky patch whose reference number is *ix* **- alloc_sky**. If *ix* is greater than zero and less than **alloc_sky** then *ix* is the object reference number for a program or fiducial object. Integer array.

All of the arrays in the three lists above have been dimensioned to some maximum number of elements. The actual dimensions are listed in the include file 'af2_par.inc'. I realise that this is inelegant in the extreme and that I should have written it so that the space was allocated dynamically at run time (in the same way that the workspace is allocated for the placement routines). But this was the way that the original program was written and to make such a fundamental change would have been a major piece of surgery which time didn't allow.

Appendix F

Post-observation: IRAF reduction

F.1 Introduction to WYFRED

In this document we describe **wyf_red**, a data reduction task specialised for the extraction of the multifibre spectra generated by WYFFOS . This is an IRAF script task which is based on the generalised fibre reduction task **dofibers** which was written by Frank Valdes[1] at NOAO. It does differ from **dofibers** (and its variants) in a number of important respects:

CCD processing With tasks such as **dofibers** you are expected to have done the CCD processing *before* using the relevant extraction task. This is not the case with **wyf_red** which will do any requested CCD processing itself. You can, of course, do this yourself if you want.

Aperture identification One of the major headaches of multi-object spectroscopy is the bookkeeping involved. The way that tasks like **dofibers** solve this problem is for the user to define an **aperture identification table** which cross references the spectra with a title and an object type (object, sky, *etc.*) The problem is solved similarly by **wyf_red** with the exception that the aperture identification table is generated automatically by information in the input file header. (This is especially useful for WYFFOS , since the header information does not form a one to one correspondence with the output spectra as a number of the fibres in the large fibre bundle were accidently jumbled before being cemented to the slit configuration.)

Header compression At the time of writing the files generated by WYFFOS and AF2 contain almost 3000 FITS header items. This is massive overkill for most applications and most packages will be slowed down by the sheer weight of such a big header. For this reason **wyf_red** will rewrite the header of an input file into a 'compressed' format. No information is lost in the compression and the routine which does the compression can spot occasional mistakes in the header records which at the time of writing still manage to sneak into the files (although these are very few). Appendix F.11 gives a detailed description of the compressed header format and how it relates to the raw header.

[1] The author wishes to thank Frank Valdes for all his help and advice and for his permission to ransack is scripts

File matching With multi-object spectroscopy the onus is usually on the user to make sure that (for example) the object frames and the offset sky frames which are fed to the reduction task were done with the same fibre configuration. Again this is sorted out automatically by **wyf_red** using information contained in a standard WYFFOS header. This gives the user considerable freedom in how the files to be reduced are specified. This will be discussed in more detail in section F.4.

Sawtooth correction Most fibre optic spectrographs have the fibre ends in a colinear arrangement at the slit end. This means that (ignoring the distortion of the camera) a given position in the spectral direction will be at roughly the same wavelength for each spectrum. However for WYFFOS , in order to try and save space at the detector, the fibre ends were placed in three parallel rows, which means that a given point in the spectral direction can have three (approximate) wavelengths. **wyf_red** does this 'sawtooth' correction explicitly as each spectrum is being extracted by shifting its world coordinate system by an amount which approximately reflects the amount of offset at the slit configuration. N.B. The need to make this correction means that for the most part tasks such as **dofibers** will fail for WYFFOS data.

End finding WYFFOS can observe at resolutions so low that the spectral range of the spectrograph is actually smaller than the total spectral range which could be accommodated on the chip. While this isn't necessarily a 'problem' for extraction, it can be a problem when it comes to doing the spectral flat fielding – that is a sharp 'cliff' at either edge of the mean flat field spectrum is nearly impossible to fit correctly and will introduce numerous wiggles into the resulting spectra, no matter how high an order polynomial or spline is used. Once **wyf_red** has determined the positions of all of the spectra and their distortions in the spatial direction using the aperture reference image (see below) the spectra on that image can be (at the users discretion) extracted and added together to form one mean spectrum. A routine then would look for sharp edges and decides whether or not the spectra need to be trimmed. This can also be done by hand using a cursor. If the user decides not to search for these cliffs the spectral limits are defined automatically according to the sawtooth correction shifts. Since most users will *not* observe at such low resolutions the default is to skip looking for these cliffs.

Arc line identification The "sawtooth correction" means that **wyf_red** can't use the straightforward scheme which **dofibers** uses for the identification of arc lines. Therefore in **wyf_red** we have three different schemes to choose from, a completely automatic algorithm (everything is done for you), a semi-automatic algorithm (you identify the lines in one spectrum and all the lines in all the other spectra are done for you), and a fully manual algorithm (you identify the lines for each spectrum – rather tedious). These will be discussed more fully in section F.4.

In the following section, I describe some of the basic aspects of multi-fibre spectroscopy. This is intended for people who are new to the subject and more experienced observers can probably skip over it. In Section F.3, I describe what you need to do before getting started with **wyf_red** (this is recommended reading). Section F.4 gives a full description of how to use **wyf_red**. Section F.5 includes a list of other applications which are available in the WYFFOS package. These may turn out to be quite helpful and in particular it is highly recommended that you read about the application **wyfgeom** before you start. In Appendix F.7 a description is given of all the parameters for **wyf_red** while in Appendix F.8 a description is given of all the parameters in **wyfpars** (a pset of parameters which rarely need to be changed in **wyf_red**). Information on how to access the parameters in **wyfpars** for those who are unfamiliar with IRAF psets is also given. The package parameters for **wyffos** are included in Appendix F.9. Appendix F.10 lists which header items are being accessed and why. Finally Appendix F.11 explains the compressed header format.

F.2 Aspects of Multifibre Spectroscopy

F.2.1 Bias Subtraction

A "bias" level is introduced onto a CCD chip in order to ensure that the chip is working in a linear regime. A bias also guards against negative numbers at readout which have a statistical chance of occuring in regions of low emission. This bias level must be determined and subtracted out of an input CCD frame before any further analysis can be carried out. This can be done one of two ways. The first is to look at the overscan region of each frame and do a statistical analysis to find the mean bias and then to subtract this constant off the whole rest of the frame. The second is to average a sample of bias frames (frames taken with zero exposure time) pixel by pixel to produce a mean bias frame. This mean frame is then subtracted (pixel by pixel) from each input image. This is the method to choose if you believe there is structure in the bias of your chip. It is important to realise that if you want to use a mean bias frame you need to have at your disposal a good number of individual bias frames in order to form the mean frame (say at least 10, preferably 20). This is in order to beat down the readout noise in the individual bias frames to such a level that you are not adding a significant amount of noise to your program images by doing a frame subtraction.

F.2.2 Aperture Definition

One of the most critical things to get right in multiobject spectroscopy is the determination of the aperture information for each spectrum. That is the location of each spectrum, the spread of each spectrum in the spatial direction and the distortion of the spectrum in the dispersion direction. The latter is quite important for instruments such as WYFFOS where owing to the field distortions introduced by the optics of the system a spectrum won't necessarily line up along the rows/columns in the dispersion direction (just the opposite is usually the case and spectra can be very distorted, especially near the edge of a frame). Getting the aperture information is also crucial as the ancillary information for each object observed, such as the (α, δ), the object name, *etc.*, is stored in the header of the input frame and it is important for bookkeeping that each spectrum is cross-referenced with the correct header information.

Normally, objects observed with instruments like WYFFOS are quite faint and determining the aperture information for such a frame can be very difficult. This is where an "aperture reference frame" can come in quite handy. This is a high signal/noise frame from which the apertures can be defined and might typically be a flat field exposure. Note that any frame can be used as an aperture reference for another frame (a program frame), provided that the fibres used in the program frame are also illuminated on the aperture reference frame.

One final point to consider with respect to aperture definition is the order in which the fibres appear on the output frame. In a WYFFOS frame the spectra are vertical, so what needs to be considered is whether an object observed in the first available science fibre will appear on the right or the left hand side of the output frame. This depends upon which corner the CCD is being read from. If you don't know which way around the fibres are, then you must contact your support astronomer to find out. The application **wyfgeom** described in section F.5 can help you set the appropriate defaults in **wyf_red** once you have this piece of information.

F.2.3 Scattered Light Correction

All spectrographs have scattered light and WYFFOS is no exception. It is important to get rid of this scattered light, especially if the objects you are observing are faint. **wyf_red** uses the IRAF routine **apscatter** to estimate and subtract out the scattered light component. This is done by fitting polynomials or splines to the emission along the lines and columns of the image, but ignoring the places where the aperture definition says there should be a part of a spectrum. Once **apscatter** has successfully modelled the excess light between the spectra it interpolates to the regions where the spectra are located and then subtracts that model off the frame. It is highly recommended that you fit at least one frame by hand since you will need to choose the order of polynomial/spline which fits your scattered light best.

F.2.4 Flat Fielding and Throughput Correction

This is an alias for the removal of the multiplicative effects that originate from instrumental signature, the throughput of the fibres, the vignetting (which depends upon the position of the object in the field), and the pixel to pixel variation in response within the chip itself. The instrumental signature and the pixel to pixel variation are found through flat field exposures (exposure of a uniform light source through the fibres). These should be very high signal to noise frames as the pixel to pixel variation is usually only of the order of a few percent. The fibre throughput and vignetting corrections are found through exposures of an 'offset sky' frame. These are frames of sky taken very near to a program region *with the fibres in the same configuration as the program region*, but only of sky. The signal/noise ratio needn't be very high as we need only consider the mean counts per fibre. It is good observing practice to take 2 or 3 offset skies per region as a precaution against starlight accidently falling down one or more of the fibres. The relative transmission of each fibre as seen from this total flux per fibre relative to the average flux of all the fibres will be the product of the field vignetting and the fibre throughput. A constant is used to normalize the results of the vignetting–throughput correction so that in the mean the response is 1. This ensures that the number of counts on a frame remains roughly the same after flat fielding. For **wyf_red** (as with **dofibers** and its relatives) the flat-field frame and the vignetting–throughput frames are combined to form one 'response' frame.

F.2.5 Extraction

By 'extraction' we mean the summing up of the spectral pixels along the spatial direction into a final one-dimensional spectrum. Admittedly there is a bit more to it than that, especially when low signal/noise data are being extracted. The WYFFOS package uses a method called 'optimal extraction' which attempts to give lower weight to regions of relatively low signal/noise than to those regions with relatively high signal/noise. The net result is that in low signal/noise regions where the signal is of the same order as the readout noise of the chip, the lower weights mean that the contribution to the final spectrum of the readout noise is significantly reduced.

In fact the term 'optimal extraction' refers to methods which attempt to maximise the possible signal/noise in the output spectrum.

Because of the way that optimal extraction works, it can predict roughly the number of counts it expects to find in each pixel of a spectrum depending upon the wavelength and its position in the point-spread function. Thus pixel values which are significantly higher than the predicted value can be removed as these are likely to be cosmic ray events. Optimal extraction can cause the removal of many such spurious pixels and result in a much 'cleaner' final spectrum (although it may not still be completely free from cosmic ray events). It is, however, possible to switch off this cleaning algorithm.

F.2.6 Arc line Identification and Dispersion Correction

Arc line identification is one of the most boring aspects of spectroscopic data reduction. It is rather important though if you want to wavelength calibrate your spectra and sky subtract. For WYFFOS there are three different ways in which arc lines can be identified:

Automatic line identification A routine which automatically identifies arc lines has been included for WYFFOS . This works by a simple projection method and uses information in the headers of the files as a starting point. For arc spectra with a reasonable number of lines (say greater than about 5) this works very well and it is the preferred way to do arcline identification.

Semi-automatic line identification The automatic algorithm may fail for some arcs. Either the number of lines is too small or perhaps the header information is sadly off the mark. Semi-automatic line identification can save the day in a rather painless way. This entails the user identifying lines for one spectrum and the results of this being used to identify the lines in the rest of the arc spectra automatically. This is currently the default setting.

Fully manual line identification If the above two methods fail, there is always the option to identify the lines for each arc spectrum manually. This should not be necessary very often and the reasons for possibly having to use it will be explained later on.

Once the arc lines have been identified, it has to be decided which arc frame applies to which program frame. The assigning of reference arcs is done using automatic criteria which the user can change. Generally what happens is that if there are two arcs available, one on either side of the program frame (chronologically speaking) then the mean solution from both of these frames is taken for the program frame. If only one arc is available, then that arc frame's solution is applied directly to the program frame. 'Dispersion correction' is the act of taking the dispersion solutions found in the reference arcs, applying them to program frames and then using those solutions to rebin the input spectra so that they are on a linear or log linear wavelength scale.

F.2.7 Sky Subtraction

There are two ways normally to subtract the sky contribution from the fibre spectra. Note that if you want to do a sky subtraction, then you must also do a wavelength calibration!

Simultaneous sky exposure When an object field is configured it is quite normal to use some of the fibres to monitor the sky background. Under most circumstances using these sky fibres to form a mean sky spectrum is the preferred way to do sky subtraction. It is however essential to have at least 10 to 20 dedicated sky fibres in order to get a meaningful mean sky spectrum. Note also that in regions where the sky brightness is very non-uniform (for example, for observations of stars in external galaxies), it is essential that the sky fibres be placed in representative places and that the sky subtraction is *not* done with a mean sky spectrum.

Separate sky frames These are generally already being taken with each program frame, as having an offset sky exposure is essential for the determination of the throughput and vignetting corrections. It is possible to extract the sky frames as an 'object' frame and thus do a spectrum by spectrum subtraction in order to take out the sky contribution from the program spectra. This can be a dangerous way to do sky subtraction if the offset sky is of low signal or in circumstances where the sky background is varying on reasonably short time scales (e.g. bright of moon or in conditions of patchy cloud). It can be however quite a useful way of checking the sky subtraction as done with the simultaneous sky fibres. It is also the only way of doing sky subtraction in the event that the observer has not allocated any sky fibres at the configuration stage.

F.2.8 Residual emission line removal

Sky subtraction is never perfect. Reasons for what appear to be bad sky subtraction include the fact that the vignetting or dispersion corrections may not have been done very well (perhaps there are hardly any lines?). The line spread function may also depend upon the fibre's position relative to the centre of the field. Any of these could lead to sky emission lines being present as either residual emission (not enough sky subtracted off), absorption (too much sky subtracted) or as p-cygni type profiles (bad dispersion correction). Of course, just because you see these effects doesn't necessarily mean that you have bad sky subtraction – a certain amount of these effects may be present even in well sky-subtracted data. As such it is worthwhile getting rid of the residual emission from sky lines just to improve the presentation of the spectra. This is achieved by the user supplying a file with the wavelengths of the sky lines to be 'tippexed' out and the number of Angstroms on either side to define the region of the cleaned line. Note that this won't get rid of the rogue cosmic ray hits, as these don't occur in predictable locations.

F.3 Getting started

wyf_red is an IRAF task which is composed largely of scripts. This means that much of the functionality of **wyf_red** comes from other IRAF tasks from various other packages. The packages most used by **wyf_red** are **onedspec** and **apextract**. Looking at the help files for these two packages (especially the former) could be *very* beneficial.

Do you know anything about IRAF? Have you ever used it before? If the answer to either of these questions is 'no', then you might consider trying to find out a little more about IRAF before you proceed with **wyf_red**. A very useful document called *A Beginner's Guide to Using IRAF* is available (see the reference list at the end of this document) and a few hours spent reading it will certainly make the learning curve much more bearable. Even experienced IRAF uses may learn a trick or two, so it might be worth a skim even if you are pretty sure you know what you're doing.

Next check and see if you have **wyf_red** on your system. It is in a package called **rgo** which you should see when you first get into the IRAF **cl**. If you don't see **rgo** or if after loading **rgo** you don't see a package called **wyffos**, then you either don't have the **rgo** suite of packages, or you have an old version. In that case contact the author in Cambridge for an up to date version and get your local IRAF manager to install it for you (it should only take a few minutes).

Assuming now you have access to **wyf_red** you'll need to read your files to disc. One major hair in the WYFFOS pie is the enormous header which is generated at the telescope. A standard setup of IRAF will cause a large section of that header to be destroyed and as **wyf_red** really needs most of what is there, then you are likely to run into trouble unless you take a few precautions. The 'offending' IRAF environment variable is called 'min_lenuserarea'. This defines the maximum size of an IRAF file header. When you load the package **wyffos** the value of 'min_lenuserarea' is automatically bumped up to a level which will accommodate raw WYFFOS headers. So before you read your FITS tapes (using **rfits**) it will be worthwhile loading the **wyffos** package to be on the safe side. If you don't want to load the **wyffos** package, you could change 'min_lenuserarea' to a safe value, e.g. `cl> reset min_lenuserarea = 300000` , or you could change it in your *login.cl* file. Once you have sorted out the 'min_lenuserarea' problem in whatever way you want, you can then read in your files.

F.4 Using wyf_red

In this section we describe how to use **wyf_red** to reduce WYFFOS data. Just what you mean by 'reduce' will determine how much of this you need to read. Currently **wyf_red** will CCD process, aperture identify, scattered-light correct, flat field (including throughput and vignetting corrections), extract (including optional cosmic ray removal), dispersion correct, sky subtract. Optionally, residual sky line emission can also be removed ('tippexing'). These topics will all be discussed roughly in turn. If after reading this section you are still confused, have a look at Figure F.1. This is a diagram which indicates roughly what gets done to your data and when it happens.

F.4.1 Input files

One of the first questions that anyone asks when using a new piece of software is "what files do I need?" There are four parameter prompts which need to be answered with the names of files.

The parameter *input* can specify a wide range of files. In order to reduce an object frame you need to have at least one object frame and an offset sky frame (for the throughput correction). If you want to do dispersion correction, you'll need an arc frame as well. At its most basic, *input* must specify all of the object data files. **wyf_red** looks in the headers of the files specified by *input* and decides which files are objects, offset skies and arcs. If, for example, you don't specify an offset sky for a particular object region in the *input* list, then **wyf_red** will look in your current directory for an appropriate offset sky frame. If it finds more than one, then it takes the one which is chronologically closest to the object frame. Similarly with arc frames – if none are specified, **wyf_red** will search for one. Conversely, if, for example, there are two offset sky frames which are appropriate for a given object frame and you want to make sure that one particular one is chosen, then specifying it in the *input* list will mean that the other one will be ignored. (**wyf_red** uses the header parameter *af2fldnm* to decide which offset skies are appropriate for which object frames. See Appendix F.10 for more details.) You can even specify the input list as "*.imh". If you are doing bias subtraction using a bias frame, then you can specify the bias frames in the *input* list. If you don't specify bias frames and you want to do a bias frame subtraction, then **wyf_red** searches the current working directory for bias frames. The same applies for flat–field frames. They can be specified on the *input* list, but this isn't necessary.

The second file parameter is *apref*. This is the aperture reference frame, as described in section F.2.2. As mentioned before, this can be almost any frame, so long as it has reasonably high signal to noise and so long as every fibre which has data in the object frames is illuminated in the aperture reference image. If, for example, you are reducing an object frame with reasonably bright objects, then the object frame itself could serve as an aperture reference. Otherwise, an aperture reference could be a twilight sky or flat field exposure.

The last two file parameters are *mbias* and *mflat*. If you want your bias estimate to be determined by the mean of a number of bias frames, then *mbias* is the name of the mean bias frame. If that file exists, then it will be used to do the bias subtraction. If it doesn't then it will be created by forming a mean of whatever bias frames have been specified in the *input* list. If none have been specified in the input list, then *mbias* will be formed from all available bias frames in the current working directory. If *mbias* is left blank, then the bias will be determined for each frame individually along the overscan region of the frame. **wyf_red** should have all the necessary information about the chip at its disposal, so there shouldn't be any problem with determining the location of the bias strip. Similarly, if *mflat* is specified, then any flat-field frames which have been either specified in the *input* list or (failing that) which reside in the current working directory will be combined to form a mean flat frame. If *mflat* is left blank then the flat-fielding will not be done. However the throughput and vignetting correction will still be done with the offset sky exposure.

F.4.2 Aperture definition

As mentioned before, aperture definition implies locating each spectrum and tracing its spatial distortion. Although you don't have to, it is highly recommended that for the first few regions you reduce, you should do this bit by hand (set the parameter *w_interact* to 'yes'). If you do, you will be presented with a graph which has a cut through the aperture reference at the middle of the frame. On top of each peak should be a number which has been preassigned to the aperture. This is where things could get a little tricky. If you are using a flat-field exposure then there is a pretty good chance that all of the fibres will be illuminated with the exception of the broken and disabled fibres. At the time of writing 18 fibres have been disabled from the large fibre bundle. Twelve of these are on either end of the chip, which means you shouldn't notice the fact that they are missing. There may be some apertures which the finding algorithm has missed. You should mark these with the cursor (using keystroke 'm'). If you don't like the scale of the plot, you can expand it by using the 'window' cursor function. This is done by typing the letter 'w' and then 'j', 'k', 't', 'b' or 'a'. 'j' and 'k' define the left and right of the window you want respectively while 't' and 'b' define the top and bottom of the window. 'a' requests that you go back to the autoscale mode which you started with. As with most cursor mode operations in IRAF you can get a full list of keystroke operations by typing '?' at the cursor prompt.

Getting the aperture number right is also rather important. This is because the amount of shift given to each spectrum for the sawtooth correction depends upon the aperture number. It's also important for making sure that the cross reference to the header information about that fibre is correct. The aperture location algorithm has information on the spacing between each spectrum, so it usually does a pretty good job of assigning aperture numbers. One thing you should be aware of is that the 'aperture number' **is not** the same as the spectrum number. For example, the first spectrum (namely the left most spectrum on the plot) will not be called aperture number 1 in general. At the time of writing the first nine program fibres in the large fibre bundle have been disabled. Thus the first fibre which can possibly be allocated is number 10. You shouldn't change this numbering system for the reasons mentioned above until after you have finished using **wyf_red**. You can then renumber the apertures using the routine **scopy** in the **onedspec** package. If you are in doubt about which fibres should be present in your data, you can always refer to the aperture identification table which **wyf_red** will have generated. This table will have a name which is the concatenation of the aperture reference file name, the field name (as specified in the header item 'af2fldnm') and the string 'apid'.

Once you have identified all of the apertures, then you type 'q' to get out. You'll then be asked if you want to fit the trace interactively. This shouldn't be necessary. As with most yes/no queries you can answer with either upper or lower case. An answer in lower case will mean that that answer will will only apply to the current spectrum and you will be asked again the next time around. Answering in upper case means you won't be prompted again.

F.4.3 Scattered light correction

If you are doing your reductions interactively, you will be asked if you want to fit the scattered light for each frame by hand. You should probably do so for the first frame at least in order to make sure you get it right. If you opt to do so, then you will first get a plot of a cut across the dispersion at the middle of the frame. The regions where the aperture definition says there should be a spectrum have been ignored so that which is left over should be representative of the scattered light on the image (this is why the cut won't look like what you see when you are doing the aperture definition). A fit will be done to the emission – the fitting function and order will be displayed at the top of the graph. If you wish to change the function or its order then you can do so with the commands `:func <functionname>` and `:order <order>` respectively. As usual the command '?' will give a listing of all the keystroke commands. Once you are happy with the fit, you can exit by typing 'q'. At this point you will be prompted with a question that asks whether you want to quit or whether you are interested in seeing another line. You might want to have a look at another line to make sure that the fitting parameters you decided upon for the first fit apply equally well to other lines. Once you are happy with the fits to the rows, there will be a brief pause and then you'll be presented with a plot of the modelled emission along the middle column. You can then define fitting parameters for the fits in the vertical direction in the same way as you did for fitting the rows.

Once you have defined the fitting parameters for the first file **apscatter** will go away and model the scattered light for the first file. You will then be prompted for each of the following files to see if you want to redefine the scattered light model. You may feel that this is not necessary, but you should be aware that the scattered light profile from an offset sky will most likely be very different from that of an object frame. For that reason **wyf_red** takes the precaution of asking.

It is possible to fit the scattered light to arc frames. In general this shouldn't be necessary. However in extreme cases the scattered light may affect the baseline profile of the arc spectra. The re-identification algorithm (which is a simple cross-correlation) that is used when **autoid** is 2 can then return spurious results.

F.4.4 Flat fielding and throughput correction

Although they are both multiplicative corrections and hence can be considered at the same time, flat fielding and throughput corrections address two very separate issues. Flat fielding will only be done if you specify a mean flat field with the parameter *mflat*. As was previously mentioned, this is generally done in order to remove the small pixel to pixel variations in sensitivity of the CCD. You can, however, choose to remove the instrumental signature by using a flat field as well. If you plan ultimately to flux calibrate you spectra (this is **not** currently covered by **wyf_red**, by the way), then you probably don't want to remove the instrumental signature, since that will go away in the flux calibration. You are given the choice of fitting a function to the mean flat field and then dividing this function through the individual flatfield spectra (*fitflat* is 'yes'). If you choose to do this, then the instrumental signature will remain in your program objects, but the pixel to pixel variations will be removed. If *w_interact* is 'yes' then you can do this fit interactively. Otherwise the fit will be done automatically using a function as specified in the *wyfpars* pset (see Appendix F.8). The flat fields will be normalised so that the mean value of all the flat fields is unity. This ensures that in the mean the total number of counts on the frame remains the same after flat fielding as before.

As mentioned before, the throughput/vignetting correction is done using the mean counts in an offset sky exposure. It is quite important that an offset sky that was taken with the fibres in the same configuration as the program frame is used since the vignetting suffered by a given fibre will depend upon its position in the focal plane. A throughput/vignetting correction is computed for each fibre based on the mean value for the offset skies (again, normalised to unity). If a flat field is being used, these values are multiplied into the flat field frame before the program frames are flat fielded. If not, a throughput correction frame is created and this is divided into the program objects to correct for throughput/vignetting.

F.4.5 Extraction and cleaning

The object spectra will be extracted using a method commonly known as 'optimal extraction' or 'variance weighted extraction' (see reading list of references on optimal extraction). One of the advantages of optimal extraction is its ability to recognise possible cosmic ray events and delete them. This will be employed if the parameter *clean* has been set. Not all cosmic rays will be excluded in this way, but it does get rid of most of them and the extra expense in processing time is well worth it, especially for faint objects with long integration times.

F.4.6 Dispersion correction

If you want your spectra to be put on some sort of wavelength scale, then obviously you will need at least one arc reference image and you will need to set the parameter *dispcor* to 'yes'. You will also need a list of the available lines for the particular arc lamp that was used during the observations. There are a number of standard line lists in the directory **wyffos$linelists/**. If you don't find the one you need there, then you can create your own and give **wyf_red** its location and name using the parameter *coordlist*. You have to choose what level of automation you want for the arc line identification as well. If you have an arc with only a few lines in a whole spectrum, it is perhaps best to steer clear of the automatic line identification algorithm, since it works using a statistical method to decide on whether a solution is valid or not, and having only a few lines will not give a good statistical measure. You make the choice of algorithm by setting the parameter *autoid*. The values *autoid* can take are as follows:

1 Use the fully automatic line identification algorithm. This uses information in the header and a projection algorithm to define the dispersion and central wavelength. No interaction is required from you.

2 Use the semi-automatic line identification algorithm. For this you identify and fit an arc for one spectrum. You would be well advised to have a look at the help file for the task **identify** before attempting this. Then **wyf_red** goes away and finds all the lines in the rest of the spectra and taking the sawtooth correction into account does a fit for each.

3 Do each arc spectrum manually. This can be quite a bore, but may be necessary on some occasions. For example if you use an arc lamp with only 2 or 3 lines (which probably precludes your using the automatic algorithm) and if the number of fibres used is quite small, then the variation in the position of the arc lines caused by the optics of the system may be large enough such that they cannot be tracked with such a sparse sample of fibres, even when the sawtooth correction has already been applied. In this case you are required to identify and fit the lines in one spectrum as with the previous item. But then each of the following spectra will be presented to you on a rough wavelength scale based on the fit done for the first spectrum. It may then only be necessary to mark one arc line and allow **identify** to shift the spectrum (using the keystroke 'g'), so you should be able to go through the spectra reasonably quickly. Again you are advised to look at the documentation for **identify** before you attempt this.

Once the arc line identification is done, then **wyf_red** will attempt to wavelength calibrate the arc spectra. When it comes to dispersion correcting the object data, **wyf_red** makes a formal decision as to which arc frame should be used in reference to the object frame (see Appendix F.8 for more details). All spectra in the object frame are then dispersion corrected.

F.4.7 Sky subtraction

If the objects you are observing are intrinsically faint, then getting the sky subtraction right is obviously a very high priority, even in dark time. For this reason **wyf_red** allows you a certain amount of latitude in this area. The "standard" way to do sky subtraction with multi-object spectroscopy is to combine all of the dedicated sky fibre spectra (the ones taken simultaneously with the object spectra) into one sky spectrum. The combination is done in such a way as to remove cosmetic defects such as cosmic rays. Then this mean sky spectrum is subtracted from each of the object spectra. There is a danger here that at least one of the sky fibres may have been accidently placed in the vicinity of a reasonably bright object. This is probably alright given that the algorithm that does the cleaning of the mean spectrum will probably reject most of the pixels from such a spectrum. If you really want to be sure, you can edit the sky spectra with the parameter *skyedit*. If this is set to 'yes' then before sky subtraction is done, the program will try and establish which spectra should be used to form the mean sky. It does this by combining all of the sky spectra into a mean and examining the results obtained by subtracting this mean from the individual sky spectra. If mean residuals are too high or two low, then the sky spectrum is rejected. If the mean residuals on the blue end are much different from those on the red end, the spectrum is rejected on the basis of curvature. All spectra with very low fibre responses are also rejected as using these will just add noise to the program spectra. If *w_interact* is 'yes' then you will get a list of all of the sky spectra and the reason that any of them might have been rejected. You will be asked to confirm the result. If you don't like the result, then you can always answer 'no' here and type in the aperture number of the spectra you want to reject.

Another way to do sky subtraction is to use the offset sky exposures. You can extract the offset skies as though they were objects by setting the parameter *skyobj* to 'yes'. You then need to scale the sky spectra by the ratio of the object and sky exposure times (these are in the header item 'exposed') using the task **sarith**. Finally use **sarith** again to subtract the scaled offset sky spectra from the object spectra. Note that when subtracting the mean sky spectrum **wyf_red** will put a flag into the header of the object frame which says that it has been sky subtracted. This is to protect you from accidently trying to sky subtract a frame twice. Thus the method just outlined whereby you subtract offset skies outside of **wyf_red** will *not* provide this sort of protection, so beware!

One last point is worth considering is whether the 'sky' you wish to subtract is not just 'sky' but also contains a contribution from something like the background light from an extended object. Such a case could arise if for example you were observing globular clusters in the halo of a nearby galaxy. In this case you will have to do your sky subtraction much more carefully and instead of using **wyf_red** you should consider much more basic tools like **scopy, sarith** and **splot** in order to make sure you get it right.

F.4.8 Tippexing

As mentioned before it is quite often desirable to remove remnants of sky emission lines after sky subtraction. This is done setting the *tippex* option to 'yes' and supplying the name of a 'tippex' file in the parameter *tfile*. A tippex file needs to have two items per line – the wavelength of the feature to be removed and the half width of the feature. If, for example, the file has the entry '6300.0 5.0' as one of its lines, then the region 6295 to 6305 will be tippexed. You can have as many entries in a tippex file as you want.

F.5 Other WYFFOS applications

The **wyffos** package contains several other applications apart from **wyf_red**. These are described here. All of these routines have help files which can be accessed from within IRAF.

F.5.1 wyfgeom

The orientation of the spectra on the output frame can vary depending upon the chip is read out at the end of an observation. Although it is highly unlikely that this will change during the course of a run, it may well change between runs. It is therefore vital that you know which way

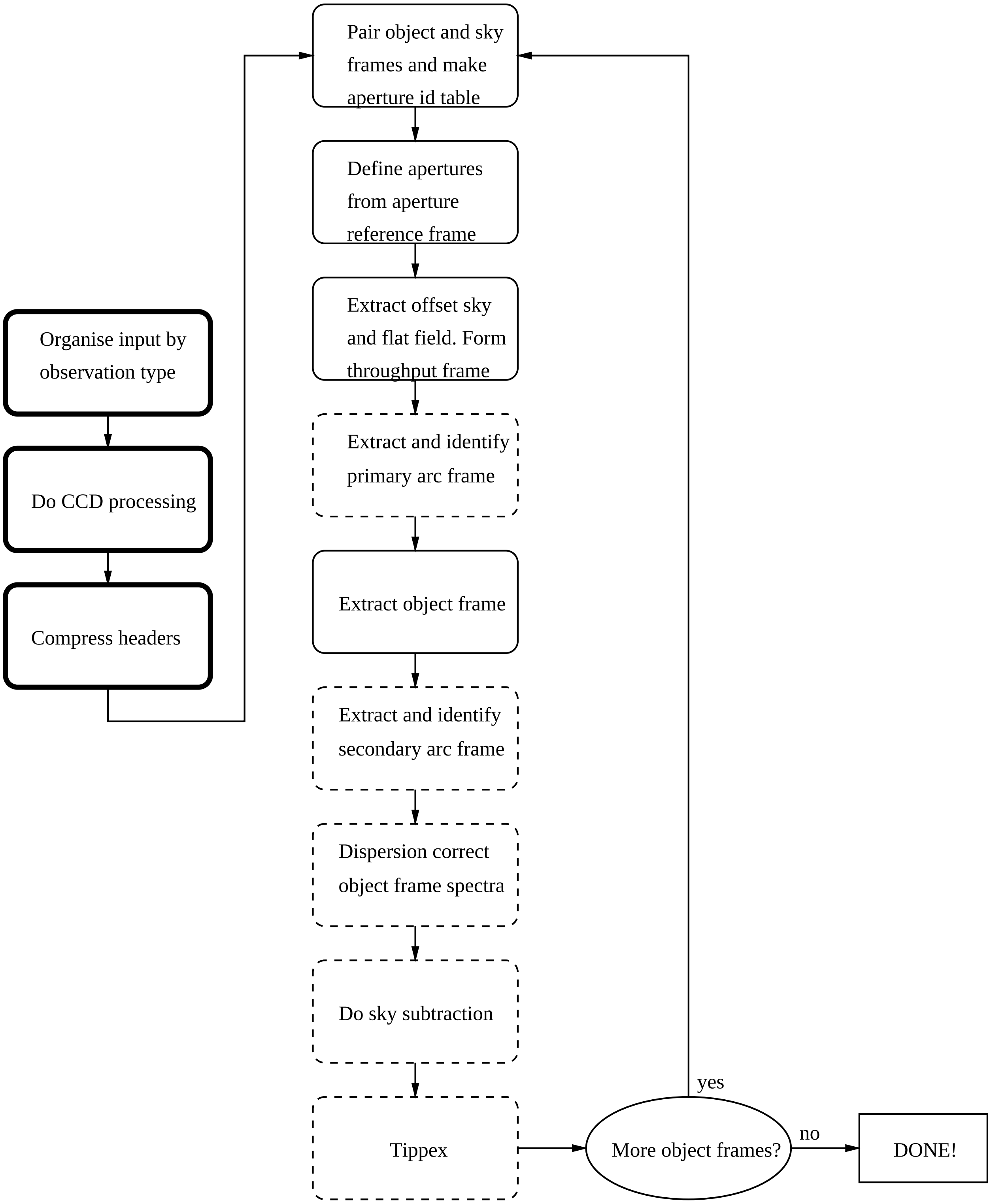


Figure F.1: A rough flow diagram of **wyf_red**. The heavy boxes are tasks that are done on the input data as a whole. The dashed boxes are only done if the user wants to dispersion correct the data. The term 'extract' here includes correcting for scattered light if the user has opted to do so.

around the fibres are on the output frame. The more crucial piece of information is whether the fibres go from right to left or left to right on the output frame (in the numerical sense). For example, does the first fibre appear on the right or left hand side of the chip? This is critical since the numbering system for the fibres defined by **wyf_red** and the underlying IRAF routines will produce erroneous results if you get this backwards. That is it will assign object information to the wrong spectra and throw the bookkeeping system completely out the window. If you aren't sure which way around your spectra are, then contact your support astronomer and find out before you start working with **wyf_red** since it is a little piece of information which may save you a lot of time and heartache.

The other, less important question, is whether the spectra have a positive or negative dispersion. That is, if you plot one up, will its blue end be on the left (positive) or the right (negative)? This isn't so important unless you are using the automatic arc line identifier. You can restrict the solutions this algorithm considers to either positive or negative solutions only if you want. This will cut down the possibility of getting an erroneous solution. If you don't know 'which way is up' then you can say so and the algorithm will search both positive and negative solutions.

This routine sets the parameters *wyfpars.order* and *wyfpars.dflip*, so if you use this routine, you don't need to set these parameters yourself.

F.5.2 fibinfo

This is a routine which can help you to extract information from the header about an object which has been observed through a specific fibre. If you know which pivot number you want then this routine will unscramble the pivot and fibre numbering system for you. Depending upon whether you ask for verbose mode you can either just receive the bare essentials (pivot number, fibre number, object name, ra, dec) or all of the information which is available for that pivot.

F.5.3 fixhead

As mentioned before, one of the major pains of WYFFOS data is the enormous headers which are generated. Header compression does help, although the remaining header is still fairly big. Any file which is reduced through **wyf_red** will automatically have its header compressed. If you have a raw frame which you want to transport to another package, then you can use this routine to cut down the header size and make it such that you don't have to have such an enormous value for *min_lenuserarea*.

F.5.4 transm

This routine allows you to calculate the relative transmissions of the fibres just from one flat field image. This can be particularly useful if the fibres are all placed in a circle for the exposure. This then takes out any relative throughput differences between the fibres which might arise as a result of vignetting in the field.

F.6 Recommended reading

F.6.1 IRAF documentation

The following files might be of interest to users. All of them are available by anonymous ftp from NOAO (140.252.1.1) in the directory /IRAF/docs. There is a chance you'll find them on the Cambridge node in the directory /data/star/IRAF/IRAF/local/docs.

apex.ps.Z A description of the package APEXTRACT. This is the package which does the extraction and scattered light correction in **wyf_red**.

beguide.ps.Z A beginner's guide to IRAF. This is an excellent reference which rank beginners and experienced users alike will find invaluable. Very highly recommended!

ccduser2.ps.Z A users guide to CCD reductions. This might be useful for acquainting you with how the package CCDRED (which does the CCD processing for **wyf_red**) works.

dofibers.ps.Z A description of the task **dofibers**. The scripts which form **dofibers** were used as the basis for the scripts which form the bulk of **wyf_red**. (In a few cases they are stolen verbatim). Reading this might be useful especially if you want an alternative explanation for some of the things you might find confusing in this document.

The IRAF FAQ sheet is also a useful place to turn when you are confused. This is available on the WWW at http://IRAF.noao.edu/faq/FAQ.html

Finally, the help files for the ONEDSPEC routines are quite useful. The most helpful of these are **sarith**, **scopy**, **specplot** and **splot**. Note that the ONEDSPEC package is loaded automatically by the WYFFOS package, so all of these applications should be available to you.

F.6.2 References to optimal extraction

Horne, K, 1986, *P.A.S.P*, **98**, 609.
Marsh, T.R., 1989, *P.A.S.P.*, **101**, 1032.
Mukai, K, 1990, *P.A.S.P.*, **102**, 183.

F.7 Parameters for wyf_red

Figure F.2 shows a listing of the parameters for **wyf_red** and their defaults. Here we also give a fuller description of each parameter.

input These are the names of all of the input files for **wyf_red**. As explained in the text the list must have at least one object frame. If no offset sky is given in this list for any one of the listed object frames, then the current working directory is searched for offset sky exposures. Similarly, if you are also processing bias and flat field frames and none are

Figure F.2: Parameters for **wyf_red** and their defaults

```
        input = ""              List of input program images
        apref = ""              Aperture reference image
        batch = no              Do processing in batch?
       (mbias = "")             Mean bias frame
       (mflat = "")             Mean flat frame
      (skyobj = no)             Reduce offset skys as objects as well?
    (override = no)             Override automatic aperture info?\n
   (scattered = yes)            Do scattered light correction?
     (arcscat = no)             Do scattered light correction for arcs?
     (fitflat = yes)            Fit and ratio flat field spectrum?
       (clean = yes)            Detect and replace bad pixels?
     (dispcor = yes)            Dispersion correct spectra?
 (skysubtract = yes)            Subtract sky?
     (skyedit = yes)            Edit the sky spectra?
    (saveskys = yes)            Save sky spectra?
      (tippex = yes)            Tippex out sky line residuals
       (tfile = "")             Name of tippex file
       (splot = no)             Plot final spectra?
        (redo = no)             Redo operations if previously done?
      (update = yes)            update spectra if cal data changes?
    (listonly = no)             List steps but don't process?\n
  (w_interact = yes)            Do some of the procedures interactively?
      (autoid = 2)              What level of automation in arcline ids?
   (coordlist = "wyffos$linelists/argon.dat") Line list\n
     (wyfpars = "")             WYFFOS parameters\n
```

listed in the input list, then **wyf_red** will search the current working directory for such input files. The input list can also be used to *restrict* which files get used. For example if you have three arc frames and you want to make sure that a particular one is used to dispersion correct the object spectra in the list, then if that arc frame is specified in the input list, then it will be used and all others in the current working directory will be ignored.

apref This is the name of the aperture reference frame. An aperture reference frame can be any sort of frame, so long as it has reasonably high signal to noise. (You are, however, strongly discouraged from using arc frames for this purpose since their signal is so localised). This frame will serve to give **wyf_red** an idea of where the spectra are in the spatial direction and also of the curvature of each spectrum. You **must** specify an aperture reference!

batch If this is 'yes' then the whole of **wyf_red** will be run in the background. Note this means that none of the interactive tools in **wyf_red** can be used, so make sure that this is what you really want! If you want to run **wyf_red** in the background, then you should do it by setting this parameter and not simply by typing `wyf_red &` which will not set things up properly.

mbias This is the name of the mean bias frame. All input and aperture reference frames will be bias subtracted (unless this has already been done). If you want to subtract a mean bias frame rather than a constant then you inform **wyf_red** by specifying a mean bias frame. If this frame already exists it is used to do the bias subtraction. If it doesn't already exist, then the bias frames in the input list or in the current working directory (if there are none in the input list) are used first for form *mbias* and then to bias subtract the input list. If you wish to subtract a bias constant which is determined for each frame in the input list individually from the bias region, then leave *mbias* blank.

mflat This is the name of the mean flat field frame. If it exists, then it will be used for flat fielding the object data. If it doesn't exist, then any flat field frames in the input list or the current working directory will be combined first to form *mflat* and then to do the flat fielding of the object frames. If *mflat* is left blank, then no flat fielding will be done.

skyobj This switch allows you to include the offset sky exposures in the object frame list. That is, once they have been used to determine the throughput and vignetting correction, they will be extracted and calibrated as though they were object frames. This can be useful if you want to use these for sky subtraction or for diagnostics when things appear to have gone wrong.

override This switch allows you to override the automatic aperture identification algorithm. You are strongly advised against doing this, but in case you feel you need to, then the parameters you would then need to set are *wyfpars.nfibres, wyfpars.minsep, wyfpars.maxsep, wyfpars.width* and *wyfpars.apidtable*. See Appendix F.8 for a fuller description of these parameters.

scattered If you want to do a scattered light correction then this should be set to 'yes'. If you are doing the reduction interactively (*w_interact* is 'yes') then you will be prompted for fitting the scattered light

arcscat If you want to do a scattered light correction on arc frames then this should be set to 'yes'. If you are doing the reduction interactively (*w_interact* is 'yes') then you will be prompted for fitting the scattered light. with a cursor. Otherwise the routine will use the parameters in the psets **apscat1** and **apscat2** to model the scattered light. In general removing scattered light from arc frames won't be necessary. But in extreme cases where scattered light affects the large scale baseline profile of the arc spectra the cross-correlation routine that identifies arc lines (**autoid**= 2) will return non-sense results.

fitflat If you want to fit a function to the mean flat field, then this should be set to 'yes'. If *w_interact* is 'yes' then you will be able to fit the function by hand with a cursor. If not, then a function described by the parameters *wyfpars.f_function* and *wyfpars.f_order* will be used. See Appendix F.8 for more information on these parameters.

clean This switch allows the extraction algorithm to 'clean' the spectra of cosmetic defects, such as cosmic rays. This costs a little in processing time, but is well worth the price especially for faint objects.

dispcor If you wish to dispersion correct your data, then this should be set to 'yes'. Note that in order to dispersion correct you must have at least one arc frame available. If **wyf_red** can't find any arc frames, then it will automatically switch *dispcor* to 'no'.

skysubtract If you want to do sky subtraction by forming a mean sky from the available dedicated sky fibres, then this should be set to 'yes'. Note that the unskysubtracted data are **not** saved. So, if you are not sure about the sky subtraction, you should perhaps run the data through **wyf_red** once with no sky subtraction. Then copy the extracted spectrum frame to another file as a backup. Then rerun **wyf_red** with the skys subtraction on. **wyf_red** will know to go straight to the sky subtraction since the flat-fielding, dispersion correction, *etc.* will all be flagged in the header has having been done.

skyedit This causes the program automatically to select which sky apertures should be used in the final mean sky. If you don't agree with its recommendations, then you can change them so long as *w_interact* is 'yes'.

splot This allows you to review the extracted spectra at the end of the reduction process using the application **splot**. Again, this is a task with a large suite of keystroke commands available and the user is advised to familiarise himself with these (with the appropriate help file).

redo This switch is used to guard against redoing operations on files which have already been done. If, for example, the input list contains a file which has already been dispersion corrected and one which hasn't, then with *redo* set to 'no' **wyf_red** won't bother to redo the dispersion correction on the former. If this is set to 'yes' then everything will be redone on every file no matter how much or how little.

update This allows for redoing parts of the reduction, but only if the aperture, flat-field or dispersion information changes.

listonly If this is set to 'yes' then you will get the output you would expect to see on your screen from a proper run of **wyf_red**, but none of the reduction will actually be done. This allows for a 'dry run' in case you're not sure you've set things up correctly.

w_interact If you have set this to 'yes', then some of the setting up of the calibration information can be done interactively. Note that any of the parameters in **wyf_red** which imply interactive input cannot be done interactively unless *w_interact* is switched on!

autoid This is an integer parameter which specifies the level of interaction in the arc line identification procedure. (1) is fully automatic, (2) is semi-automatic and (3) is fully manual arc line identification. See Section F.2.6 for a fuller description.

coordlist This is name of the line list for the arc lines. This must specify the full path to the file as well has the file name. There are several of the most popular available in **wyffos$linelists/** and the user is encouraged to look there first before creating a line list.

wyfpars This is the 'wyfpars' pset. See Appendix F.8 for more details.

F.8 Parameters in wyfpars

Figure F.3 shows a listing of the pset *wyfpars*. The parameters in *wyfpars* are accessible through the usual methods for a pset, that is either scrolling down to the *wyfpars* parameter in the **wyf_red** parameter list and typing **:e** or through the command `epar wyfpars`. Below is a description of each of the parameters.

line The aperture location algorithm sums up a number of rows across the dispersion in order to define the location of each spectrum. This is the central row of the summed block of rows.

nsum The aperture location algorithm sums up a number of rows across the dispersion in order to define the location of each spectrum. This is the total number of rows to be summed. If the number is negative, then the profiles will be medianed rather than summed.

nfibres This is the number of spectra which can be found on a given frame. This is usually set up automatically by **wyf_red** and anything which you might put here will be ignored unless the **wyf_red** parameter *override* has been set. This is not highly recommended.

width This is the width in pixels of each spectral profile. This is usually set up automatically by **wyf_red** and anything which you might put here will be ignored unless the **wyf_red** parameter *override* has been set. This is not highly recommended.

minsep Fibre spectra are reasonably regularly spaced and this is the minimum spacing between two fibres. This is used to determine whether two adjacent peaks can be both spectra, or whether perhaps one of them is spurious. This is usually set up automatically by **wyf_red** and anything which you might put here will be ignored unless the **wyf_red** parameter *override* has been set. This is not highly recommended.

maxsep This is the maximum spacing between two fibres and is used to determine whether a large blank space between two spectra can be as a result of one or more missing fibres. This is usually set up automatically by **wyf_red** and anything which you might put here will be ignored unless the **wyf_red** parameter *override* has been set. This is not highly recommended.

apidtable This is the aperture identification table. See the help file for **apfind** for a full description of aperture identification tables. This is usually set up automatically by **wyf_red** from information contained in the header and anything which you might put here will be ignored unless the **wyf_red** parameter *override* has been set. This is not highly recommended.

dosaw If this is set, then the sawtooth correction will be performed automatically. Normally this should always be set to 'yes' as if the sawtooth correction is not done, the most of the rest of the calibrations will fail as well.

Figure F.3: Parameters in the pset **wyfpars** and their defaults

```
        (line = INDEF)          Default dispersion line
        (nsum = -20)            Number of dispersion lines to sum or median
     (nfibres = 126)            Number of spectra to find
       (width = 6.)             Width of profiles
      (minsep = 8.)             Minimum separation between spectra
      (maxsep = 10.)            Maximum separation between spectra
    (apidtable = "")            Aperture ID table
       (dosaw = yes)            Do sawtooth correction?
       (sfile = "")             Name of file with sawtooth ranges and shifts
       (fends = no)             Do you want to locate spectral ends?
       (order = "decreasing")   Order of apertures
      (extras = no)             Extract sky, sigma, etc.?\n\n-- DEFAULT APERTUR
       (lower = -3.)            Lower aperture limit relative to center
       (upper = 3.)             Upper aperture limit relative to center\n\n-- A
      (ylevel = 0.05)           Fraction of peak or intensity for resizing
        (peak = yes)            Is ylevel a fraction of the peak?
         (bkg = yes)            Subtract background for resizing?
   (avglimits = no)             Average limits over all apertures?\n\n-- TRACE
      (t_step = 10)             Tracing step
  (t_function = "spline3")      Trace fitting function
     (t_order = 2)              Trace fitting function order
  (t_niterate = 2)              Trace rejection iterations
       (t_low = 3.)             Trace lower rejection sigma
      (t_high = 3.)             Trace upper rejection sigma\n\n-- SCATTERED LIG
      (buffer = 1.)             Buffer distance from apertures
     (apscat1 = "")             Fitting parameters across the dispersion
     (apscat2 = "")             Fitting parameters along the dispersion\n\n-- A
     (weights = "variance")     Extraction weights (none|variance)
        (pfit = "fit1d")        Profile fitting algorithm (fit1d|fit2d)
   (readnoise = "READNOIS")     Read out noise sigma (photons)
        (gain = "GAIN")         Photon gain (photons/data number)
      (lsigma = 3.)             Lower rejection threshold
      (usigma = 3.)             Upper rejection threshold
     (nsubaps = 1)              Number of subapertures\n\n-- FLAT FIELD FUNCTIO
(f_interactiv = no)             Fit flat field interactively?
  (f_function = "spline3")      Fitting function
     (f_order = 10)             Fitting function order\n\n-- ARC DISPERSION FUN
      (arclog = "autoarc.log")  Log file for automatic line id algorithm
       (dflip = -1)             Consider +ve, -ve or both dispersions in autoar
       (match = 2.)             Line list matching limit in Angstroms
         (sep = 2)              Minimum pixel separation
    (contrast = 0.1)            Maximum contrast between strongest and weakest
        (edge = 0)              Minimum distance from edge
 (maxfeatures = 50)             Maximum number of features for automatic identi
    (pkthresh = 10.)            Minimum threshold level for peaks
      (fwidth = 4.)             Arc line widths in pixels
```

Figure F.3: *cont.*

```
    (cradius = 10.)           Centering radius in pixels
    (cthresh = 10.)           Feature threshold for centring
 (i_function = "chebyshev")   Coordinate function
    (i_order = 4)             Order of dispersion function
 (i_niterate = 3)             Rejection iterations
      (i_low = 3.)            Lower rejection sigma
     (i_high = 3.)            Upper rejection sigma
      (refit = yes)           Refit coordinate function when reidentifying?
(addfeatures = no)            Add features when reidentifying?\n\n-- AUTOMATI
     (select = "interp")      Selection method for reference spectra
       (sort = "jd")          Sort key
      (group = "ljd")         Group key
       (time = no)            Is sort key a time?
   (timewrap = 17.)           Time wrap point for time sorting\n\n-- DISPERSI
  (linearize = yes)           Linearize (interpolate) spectra?
        (log = no)            Logarithmic wavelength scale?
       (flux = yes)           Conserve flux?\n\n-- SKY SUBTRACTION PARAMETERS
    (combine = "average")     Type of combine operation
     (reject = "avsigclip")   Sky rejection option
      (scale = "none")        Sky scaling option
```

sfile This is the name of the file with the sawtooth correction factors. This is automatically defined by **wyf_red**, so you needn't worry about this.

fends If **wyf_red** is supposed to locate the ends of the spectra then this parameter should be set. This may be important with low resolution observations where the spectra are smaller than the detector. See Section F.1 under the heading 'End finding' for more information.

order This defines whether the fibre numbers increase or decrease from left to right on an output image. The current value is "decreasing" which means that the lowest numbered fibres will appear on the right hand side of the output image. You can set this parameter by using the application **wyfgeom**.

extras If this is set, then you will get "extra" information in the spectrum output file. Normally the output spectral format is a 2D file with each spectrum occupying a single row. If *extras* is 'yes' then the output files are 3D with the optimally extracted specta in the first plane, a simple sum spectrum in the second and the estimated sigma spectrum in the third.

lower, upper These are the upper and lower limits of the spectral aperture relative to the centre of the aperture profile. These are normally set by **wyf_red** automatically, so unless you have set the **wyf_red** parameter *override* then anything you set here will be ignored.

ylevel, peak, bkg, avglimits These are all parameters which are essentially ignored by **wyf_red**, but were included in case it is ever necessary to allow for the apertures to be resized (see the help for **apfind** to find out what I'm on about here).

t_step This is a step in the dispersion direction between determinations of the aperture position and is used to determine the aperture trace (*i.e.* its distortion in the spatial direction).

Note, the parameter above *nsum* also gives the number of lines to sum for each of these position determinations.

t_function This is the function which is used to fit the spectral trace.

t_order This is the 'order' of the function used to fit the trace. As with the rest of IRAF, when a polynomial 'order' is requested, then what is meant is the true order plus one, e.g. fitting a constant means a value of *order* of one. If *t_function* is a spline, *order* refers to the number of spline pieces, e.g *t_function* is 'spline3' and *order* is 2, then you'll be fitting two cubic splines.

t_niterate, t_low, t_high These all refer to the fitting iterations done when tracing the spectra and are the number of iterations, the lower rejection threshold and the upper rejection threshold, respectively. The threshold parameters are in units of the fit sigma.

buffer When fitting the scattered light **apscatter** avoids the pixels which it believes to be part of a spectrum. In order that the scattered light estimate shouldn't be biassed by data from the fibres, the parameter *buffer* is used to define an extra space between the fibre pixels and pixels which can be used for estimating the scattered light. Note that the spectra are pretty closely packed and you run the risk of not having any pixels left over for scattered light estimation if you make this parameter too big.

apscat1, apscat2 These are the psets which determine the functions and parameters used to fit the observed scattered light. *apscat1* refers to the fits done across the dispersion and *apscat2* refers to the fits done along the dispersion. See **apscatter** for more details.

weights The spectra can be extracted in either a simple unweighted fashion (just a straight sum) or by variance weighting (optimal extraction).

pfit This is the algorithm used for the variance weighting. 'fit1d' refers to the method of Horne (1986) and 'fit2d' refers to the method of Marsh (1989).

readnoise, gain These are the noise properties of the CCD used. They can either be numbers of the names of header items. Only change these if you know what you are doing!

lsigma, usigma These are rejection thresholds used for cleaning cosmic rays out of spectra. They will only be employed if the **wyf_red** parameter *clean* has been set to 'yes'. The units are in sigma.

nsubaps **wyf_red** like **dofibers** has the ability to divide each fibre spectrum into a number of sub-apertures. This is done in order to correct for wavelength shifts across a single fibre. It should normally not be necessary for this parameter to be changed from 1.

f_interactiv If this is 'yes' and you are doing flat fielding, then this allows you to fit the flat field interactively.

f_function, f_order If flat fielding is done and the **wyf_red** parameter *fitflat* is 'yes' then these are the function to be fit and its order. Again 'order' refers either to the order of a polynomial plus one or the number of spline pieces.

arclog If you are using the automatic arcline identification algorithm (**wyf_red** parameter *autoid* is 1) then this is the name of a log file for the routine to use.

dflip If you are using the automatic arcline identification algorithm, you can restrict the solution space it searches by specifying whether the dispersion is positive (red end to the right on a plot) or negative (red end on the left). *dflip* takes the value of 1 for a positive dispersion, and a value of -1 for a negative dispersion. If you are not sure, then you can set the value to 0 and both negative and positive dispersions will be examined. If you use the routine **wyfgeom** then this parameter will be set for you.

match This is the maximum number of Angstroms which a wavelength in a line list is allowed differ from the value predicted by a dispersion function. If this value is not exceeded then the feature at the predicted position is said to match the wavelength in the line list.

sep This is the minimum separation in pixels allowed between two spectral features.

contrast This is a maximum 'contrast' between the strongest and weakest features in the arc spectrum. Having a contrast which is zero will mean that large numbers of possibly spurious local maxima will be identified as arc lines.

edge This is the minimum buffer distance between any arc line and the edge of the spectrum.

maxfeatures This is the maximum number of spectral features allowed in an arc spectrum.

pkthresh This is a minimum number of counts for a peak to be considered an arc line.

fwidth This is an estimate of the arc line width and is used in the centring algorithm.

cradius, cthresh These parameters are currently unused.

i_function, i_order These are the fitting function and its order used to fit the dispersion solution. As usual the order refers to the true order of the polynomial or the number of spline pieces.

i_niterate, i_low, i_high These are the number of fitting iterations and the clipping thresholds (in sigma) for the dispersion solution fits.

refit, addfeatures These parameters are not currently in use.

select This is the selection method used for defining which arc spectrum will refer to which object spectrum. See the help file for **refspectra** for more information.

sort, group, timewrap, time The first two are image header keywords used for sorting and grouping the arc frames. The second two define whether the sorting is done according to time or some other way. Again see the help file for **refspectra** for a complete description here.

linearize If this is 'yes' then the spectra will be resampled (interpolated) onto either a linear or a log-linear system. If not, then the wcs of the image will be assigned a non-linear dispersion function.

log If this is 'yes' then the output spectra will be on a log wavelength scale.

flux If this is 'yes' then the output pixels are integrated over the input pixel extent, thus conserving the flux. Otherwise the output spectrum is a straight interpolation of the input.

combine, reject These are the method used to combine the dedicated sky fibres into one master sky and the rejection algorithm used to remove cosmetic defects from the input spectra.

Figure F.4: Parameters for the WYFFOS package

```
 (observatory = "lapalma")      Observatory of data
      (interp = "spline3")      Interpolation type
     (cenwave = "cenwave")      Initial estimate of central wavelength
        (disp = "disp_app")     Initial estimate of the dispersion in Angtroms/pix
      (backup = "backup/")      Backup directory or prefix
    (database = "database")     Database
    (dispaxis = 2)              Dispersion axis
     (verbose = no)             Verbose output?
     (logfile = "logfile")      Log file
    (plotfile = "")             Plot file\n
     (records = "")             Record number extensions
     (version = "WYFFOS V1.0: Oct 1996")
```

scale This is a type of scaling which can be applied to each of the spectra. This should not be necessary to use if the flat-fielding and throughput correction have been applied.

F.9 Parameters for the wyffos package

Figure F.4 gives a list of parameters for the **wyffos** package. These are parameters which in general needn't ever be changed by the user with a few exceptions. The **wyffos** parameters are as follows:

observatory This is the observatory at which the spectra were taken if that information is not in the header keyword OBSERVAT.

interp This is the interpolant used when spectra are being resampled.

cenwave, disp These are the header parameters where the rough central wavelength and the dispersion (in A/pix) are stored.

backup When the CCD data reduction is done (bias subtraction, *etc.*) the original data will be copied to the directory specified by this parameter. This is a fail-safe in case something goes wrong.

database This is the name of the directory where aperture and arcline identification information will be stored.

dispaxis This is the axis which is parallel to the dispersion of the spectra. E.g. if *dispaxis* is 2, then the spectra are vertical.

verbose If this is set to 'yes' then you will get a bit of extra info as the reduction progresses.

logfile This is the name of the log file to which **wyf_red** will all its logging information.

plotfile This is the name of a file to which to redirect plot. This is for the most part unused.

records Dummy parameter not to be used.

version This is the version of the package you have.

F.10 Header items used by wyf_red

Below is a list of the header items which should be available in a standard WYFFOS data file and which **wyf_red** makes use of. The information for the individual AF2 pivots is also presented in Appendix F.11.

wyffeed This is the name of the fibre feed used in the observations. At the time of writing, only one feed is available (called LARGE).

ccdypixe This is the physical size of the CCD pixel in microns in the Y (dispersion) direction and is used to convert the dispersion in the header from Angstroms/mm to Angstroms/pixel. It is also used to convert standard feed information such as the spacing between spectra into pixel units.

cenwave This is a rough estimate of the central wavelength of the observation. Sometimes this is not terribly accurate, but it should at least be within a few hundred Angstroms.

dispersi This is an estimate of the number of Angstroms/mm for the spectral dispersion and is usually pretty accurate (within about 5-10%).

af2fldnm AF2 has a name for each configured field which is written to this parameter. This is used as a unique identifier for a field so that object frames and offset sky frames can be paired off. This is important as the offset sky frame must be taken with the fibres in the same configuration as the object frame in order to get the vignetting correction right.

obstype This is the 'type' of file which is defined at the telescope. The ones currently in use for **wyf_red** are: BIAS (bias frames), FLAT (dome flats), SKY (offset sky exposures), TARGET (object frames) and ARC (arc frames). Occasionally because of mistakes made at the observing console, the wrong value of OBSTYPE is written to the header. This can be corrected by using the task **hedit** to insert the correct value. The original values of OBSTYPE are placed in the headers by the telescope control software. If the arclamp is switched on and the observing command is 'arc' then the value ARC will be placed in the OBSTYPE header item. If, instead the observing command 'run' is used, then OBSTYPE will take the value TARGET and **wyf_red** will then assume that this is a program frame. It is therefore important to make sure that the correct commands are used at the observing console and if they haven't then to correct the values of OBSTYPE *before* attempting to use **wyf_red**.

date-obs This is the civil date of the observation.

utobs This is the UT of the observation

exposed This is the exposure time of the observation in seconds

ra, dec These are the RA and DEC of the telescope for a particular exposure.

epoch This is the epoch of the coordinates.

st This the local sidereal time of the observation

ccdchip This is the name of the chip used in the observations and is used to define the data region and the bias strip.

If the headers of your files have not been compressed, then you will find the following items of data in the headers for each AF2 pivot. Note, this is not a list of *all* the header information for each pivot, just the bits which **wyf_red** eventually uses (albeit that **wyf_red** only uses them once they've been compressed). The format for the header items is "F" followed by a three digit number (with leading zeros) which denotes the pivot number, followed by the header item name (which is what will appear in the list below). For example the fibre type for pivot 30 will be stored in item "F030TYPE".

type This is the fibre type. There are four possible values: PR – program object, SK – pivot has a dedicated sky fibre, FI – pivot has a fiducial fibre, UN – pivot has a fibre which for one reason or another is not currently being used.

name This is the name given to the object by the user in the configuration file.

ra This is the RA of the fibre.

dec This is the DEC of the fibre.

mag This is the object magnitude

cmnt This is a comment string which may have been added at the configuration stage.

F.11 Compressed header format

In order to cut down the amount of space taken by WYFFOS headers we have introduced a compressed header format. Raw WYFFOS files have 16 header cards per pivot. The compressed format puts this data on at most three cards (usually on two). In a compressed header the header items are called "F" followed by a three digit number (with leading zeros) denoting the pivot number, followed by "DAT" and then followed by 1, 2 or 3. In table F.11 we give a listing of the header objects and where they can be found in the compressed format. For example, the fibre type for pivot 30 which is stored in "F030TYPE" in the raw WYFFOS format is stored in columns 44:45 in "F030DAT1" in compressed format. Note that if the comment header item is blank in the raw WYFFOS format, then the third compressed header card is not created.

Table F.1: Location of WYFFOS header items in compressed format

Old Item	Card no.	Columns	Remarks
NAME	1	1:18	Object name
RA	1	20:30	Object RA
DEC	1	32:42	Object DEC
TYPE	1	44:45	Fibre "type" (PR, SK, FI, UN)
MAG	1	47:55	Object magnitude
ID	1	57:62	Object identification code
FIBX	2	1:7	Fibre X position
PEX	2	9:14	Fibre X position error
FIBY	2	16:22	Fibre Y position
PEY	2	24:29	Fibre Y position error
FIBT	2	31:35	Fibre position angle
FPVX	2	37:43	Pivot X position
FPVY	2	45:51	Pivot Y position
STAT	2	53:53	Pivot status code
WT	2	55:60	Pivot weight
CMNT	3	1:63	Any comments in configuration file