Isaac Newton Group, La Palma

A User Guide to the INT Faint Object Spectrograph

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Chapter 1

The INT Faint Object Spectrograph

1.1 Introduction

This guide attempts to introduce the observer to the Faint Object Spectrograph (FOS) as used on the Isaac Newton Telescope (INT). No detailed attempt is made to educate the reader concerning the workings of the detector (a Charge Coupled Device (CCD)) used with FOS; if the reader is interested, more details can be found in e.g. 'A User Guide to the INT Prime Focus CCD', available in the INT control room, or from the LPUU at RGO.

Chapter 1 gives a brief description of the hardware and performance of FOS, chapter 2 details the setup and operational checks necessary to see that FOS is working properly, chapter 3 covers the operation of FOS in conjunction with the cassegrain Acquisition and Guidance (A&G) box and the INT Intermediate Dispersion Spectrograph (IDS) and chapter 4 shows the procedures contained in the online 'quicklook' reduction procedures.

The Faint Object Spectrograph (FOS) is a highly efficient fixed format CCD based spectrograph, designed for low resolution (15-20Å) spectrophotometry, over a wide spectral range. The optical design, described by Charles Wynne (Optica Acta, 1982, 29, 1557) is based on a Schmidt camera working without a collimator in the diverging beam from the f/15 Cassegrain focus of the INT (see figure 1.1). The major components are shown in figures 1.2 and 1.3). The dispersion is provided by a transmission grating and a cross dispersing prism (grism), which together give a multi-order format covering the wavelength range 3400Å to 10,830Å. As a result of locating the CCD within the camera, there are a small number of optical surfaces and minimum vignetting, which produces a system which is more efficient than most conventional spectrographs. The fixed format enables FOS to have its own set of online data reduction and analysis procedures; the observer is then able to have calibrated data within a very short time of the completion of an exposure.

FOS is located beneath the IDS, using the same slit assembly, comparison sources and acquisition and guiding facilities. The change of IDS and FOS modes can indeed be made during the night, by moving a single folding prism, and installing or removing a light tight tube. The change from one mode to the other takes less than half an hour.

1.2 Hardware description

FOS was an 'add on' to the Cassegrain cluster of instruments on the INT, the IDS and A&G units having been designed prior to Wynne's paper. It was thus necessary to find a mounting point on the IDS which did not cause flexure of the structure (FOS weighs approximately 100kg). This, combined with the small clearance between the Cassegrain cluster and the dome floor meant that a folding flat mirror had to be introduced to accommodate the long path length of the f/15 beam. Figures 1.1, 1.2 and 1.3 show FOS and its relationship to the IDS.

The FOS frame is constructed of 3mm steel plate, welded together to give a rigid structure. Flexure tests of FOS on the telescope show the rigidity is better than the design specification, the image of a spectral line shifts by only 0.03 pixels per hour in the dispersion direction as the telescope tracks through the zenith.

The folding flat is placed approximately halfway along the light path from the slit to the grism. It has a plane glass surface, with an extended blue response silver coating.

The Hartmann shutters are situated between the folding flat and the grism. They are only used in the initial focussing of the instrument, not during normal observing. They are pneumatically operated and controlled from the instrumentation computer via Camac.

The camera body has the grism at one end, the mirror at the other, with the chip between them. The body is fitted to the frame on a 3-point seat which is adjusted so the spectrum falls on the correct part of the chip.

The grism has a 150 lines/mm plane transmission grating on the front surface. A ray from the slit centre to the centre of the grating surface makes an angle of 6.892 degrees with the normal to the surface and with the normal to the grating rulings. The central ray at a wavelength of 8000Å is diffracted normal to the grating. The grism as a whole is a cemented assembly of the transmission grating, cross dispersing prisms of Schott SK5 and LF5 glass, and an aspheric corrector plate of Schott K10 glass.

The camera mirror is coated with an extended blue response silver coating and is expected to keep its high reflectivity, as the system is not let up to atmospheric pressure, except for maintenance.

The CCD is supported in the camera body by four slender arms attached to an outer ring, which is held off the camera mirror by three invar rods, resulting in an insignificant change in focus position with temperature. The focus position is initially set up by moving the outer ring in small increments, using motor micrometers controlled by a microprocessor. It is not necessary to adjust the focus position during normal observing. The camera contains an absolute minimum of electronic components, a temperature control circuit, and some capacitors for stabilisation. The pcb on which the chip sits is thus very small, minimising light losses within the camera.

The cryostat contains sufficient liquid nitrogen to keep the CCD cool for more than 12 hours, and is bolted to the side of the FOS frame, connecting via a copper cold finger through the side of the camera body to the CCD. It could be cooled to 120K, but is normally operated at 150K, stability being achieved using a small heater.

1.3 The CCD electronic system

In common with all other 'common user' instruments on the INT, FOS is controlled from the instrument computer, a Perkin Elmer 3210, via the ADAM environment. To obtain data, the chip is cleared of all previously accumulated charges, and then exposed for the required time. When the exposure is completed, the pixels are clocked out one at a time, the charge from each pixel being deposited on the gate of the output transistor, and read out as a voltage. This is amplified, and digitised to 16 bits,whence it is transmitted to the instrument computer via Camac. It is then stored and displayed. The process of reading out the chip takes approximately 30 seconds.

FOS is currently using an extended blue response GEC P8603 type chip, coated for the Observatory by ESO. This type of chip is characterised by very low internal noise, which, coupled with a small contribution from the pre-amplifier and ADC, gives a total noise of around 7 electrons rms. The overall chip characteristics are excellent, and no preflash facility is included. Details are given in appendix C. As the CCD is operated at low temperature, the thermal noise is negligible, so the charge stored in the potential well of each pixel is proportional to the number of absorbed photons.

The new chip was installed in May 1988. The chip in use prior to this was an uncoated GEC P8603 which was ineffective in the second order. The quantum efficiency of the new blue coated chip as measured at Herstmonceux is shown in Figure 1.4.

1.4 Performance

The main factors governing the suitability of FOS for astronomical observations are the spectral resolution and the efficiency. As far as resolution goes, FOS works at a lower resolution than most other conventional spectrographs. The dispersion is 450Å /mm; camera resolution with a narrow slit (0.25 arcsec) is 1.2pixels (12.8Å) fwhm, independent of wavelength along the full width of the 4 arcmin slit. Under normal working conditions with a 1-2 arcsec slit, the resolution is 15-20Å in first order (8-10Å in second order). Hence it would appear that FOS is suitable for studying emission line objects (AGN, HII regions, planetary nebulae), or continuum studies. It is questionable whether FOS is suited to studies of narrow absorption line objects (solar type stars etc.) where absorption features would fill only 1-2 pixels. The principle advantage of FOS is that it is considerably faster than a conventional spectrograph, and so is likely to be useful for those objects which are too faint for their spectra to be obtained at a high enough signal to noise in reasonable integration times with other instruments. The total throughput of the entire system (atmosphere,telescope and FOS with the extended blue CCD) in first order is 12.5% at peak. Only a small proportion of this loss occurs in the FOS optics - the throughput of the FOS minus detector is approximately 70% at blaze. The efficiency of FOS in first and second order is shown in Figure 1.5.

In Figure 1.6 we show the sky subtracted signal to noise per first order 10.7Å pixel, assuming the object occupies 3 columns of the chip, and adopting mode D operation (25 arcsec slot for sky + object). Adequate classifications of broad features (QSOs, emission line galaxies, M stars) can generally be made with a s/n of around 5; absorption line objects usually demand a s/n of better than 15. The format of the spectrum is shown in Figure 1.7. If an object is blue, the curved third order is seen to the left of the first two. This is faint; there is no software developed to make use of it.

Figure 1.1: Location of FOS relative to the IDS and cassegrain A&G box

Figure 1.2: FOS

Figure 1.3: 3 dimensional view of FOS and the IDS

Figure 1.4: The Relative Quantum Efficiency of the GEC CCD used in the INT FOS

Figure 1.5: The Efficiency of the INT FOS

Figure 1.6: The sky subtracted signal to noise per first order 10.7Åpixel, assuming the object occupies 3 columns of the chip, and adopting mode D operation (25 arcsec slot for sky + object)

Figure 1.7: The format of a FOS spectrum, assuming mode D operation (25 arcsec slot for sky + object)

Chapter 2

FOS Setup

2.1 Low level operations and calibration checks

As far as the user is concerned, FOS has no moving parts. There is no need to set up FOS in the same way that say the IDS+CCD is. In normal use it should not depart from its original commissioned configuration. There are a few simple checks the astronomer and his support astronomer can do.

2.1.1 Hardware changes

The change from IDS to FOS (or vice versa) is an operation for the duty technician or the support astronomer. If the FOS cryostat has been pumped down and cooled, the changeover time is less than half an hour. It must be made plain that if you want to use FOS when it has not been scheduled, the technical staff must have been notified via the support astronomer. The cryostat takes some hours to pump down to a reasonable vaccuum, and to cool to its operating temperature (150 degrees K), so more than a days warning is needed.

The change from IDS to FOS involves:

a) Switching the IDS detector to a safe condition

b) Removing the folding prism which was sending light to the IDS detector so that the light can enter FOS via the flat mirror.

c) Inserting a light tight tube between the IDS and FOS.

d) Changing the dekker and below slit filter slides with those specifically for FOS.

e) the camera electronics must be switched on. This involves a cable change at the Cassegrain cabinet, so the RGO CCD camera controller can drive FOS.

f) Finally the software must be re-initialised by restarting ADAM and selecting the FOS mode at the observer's console.

2.1.2 System checks

The best way to check that the instrument is operating correctly is, after having loaded the FOS software, to take a dummy exposure using the GLANCE command. This checks virtually all status lines, clears the chip, checks that the shutter opens and closes, reads out the chip into a data file, and displays the image on the lexidata display. Keep a watch for any error messages. You can monitor the CCD telemetry by the command

ADAM>TELE — this only shows telemetry values which are outside tolerance. To see all telemetry values use the command:

ADAM>TELE QUIET=FALSE

2.1.3 Focus and alignment.

Experience shows that FOS is very stable, having been removed from the cass cluster and replaced several times with no noticable change in focus and alignment (within the measurement errors). Focussing of FOS is done by moving the CCD detector in 3-D using the 3 motor micrometers (labelled s r and b). These are not adjustable in normal operation, but their status can be obtained by reading the position sensors (LVDTs) next to each micrometer. MSTAT can be used to get these values, as well as focus and tilt angles (HA,VA) of the CCD. These should be within 10 units of the specification. e.g.

ADAM> MSTAT

focus motor positions are:

MIKES=378 MIKER=481 MIKEB=291

hence FPOSIT=383 HANGLE=95 VANGLE=2

If these values are outside the tolerance, inform the support astronomer. As a further check, expose a copper-argon comparison lamp and, if available, a mercury comparison lamp, as follows:

ADAM> 2LAMP ON	Switch on copper-argon lamp
ADAM> ND 1.2	Insert filter ND=1.2
ADAM> DEKKER 3	Select 200 micron dekker
ADAM> SLIT 50	Select 50 micron slit
ADAM> GLANCE 10	Expose for 10 seconds

Using the PROFILE option in PHOTOM you can find the position and width of five lines at the following wavelengths:-

9658Å	centred	near	pixel	135,156
9123Å	”	”	”	135,206
8265Å	”	”	”	137,286
6965Å	”	”	”	141,407
5461Å	”	”	”	153,548

The line at 5461Å is from the mercury comparison lamp. All the other lines are from the copper-argon comparison lamp.

Use SLICE (from the FOS reduction package) to get accurate vertical and horizontal profiles with rectangular boxes of dimensions [2,8] and [8,2] respectively. Alternatively, use STARFIT; this routine is really designed to measure stellar images, but works at least as well on arc lines taken through a narrow dekker. Values for the chip installed in May 1988 are given in table 2.1 The centroids can change absolutely by about 0.5 pixels, and by more than 1 pixel if the folding flat has been moved. Drift with telescope attitude is about 0.03 pixels per hour, and relative stability is of the same order.

Table 2.1 focus and alignment goals (1st order)

	line	9658Å	9123Å	8265Å	6965Å	5461Å
Moments	V	155.61	205.59	285.80	407.03	547.37
method	sigma	0.65	0.62	0.60	0.50	0.59
Starfit	V	155.47	205.54	285.77	406.99	547.35
method	fwhm	1.40	1.40	1.35	1.20	1.31
	H	134.65	135.41	137.22	141.62	153.13
	fwhm	1.45	1.44	1.47	1.43	1.40

NB. V is in the dispersion direction

H is in the cross dispersion direction

The sigma/fwhm estimates are a good indication of focus if you are concerned about it, but remember that FOS just undersamples, so fwhm and 2.32 sigma may not quite agree — two different methods are used to determine these quantities, and the results will also depend quite strongly on the position of the line within the pixel.

Chapter 3

FOS Operation

3.1 Operation of FOS and astronomical considerations

3.1.1 Overview

The object of this section is to introduce the investigator to the typical commands used in operating FOS in an observing session. As stated earlier, FOS is run in the ADAM environment, and many of the commands are identical to those used to control the IDS + CCD. Examples are the RUN, GLANCE and PHOTOM commands. The commands which are missing from the FOS repertoire are those which operate many of the IDS functions, e.g. grating angles, collimator focus. Unlike the IPCS, there are few safety precautions, as it is not as 'delicate', and there is no real time display.

It should be possible to run FOS without reference to any other guide than this, although this guide cannot be exhaustive, and details of ADAM and CCD routines are to be found in the appropriate manuals.

FOS is run from the observer station, which consists of an ADAM terminal, from which all the commands are issued, a MIMIC display, which shows the status of the A&G box, slit width, above and below slit filters, and dekker positions, and a LEXIDATA, on which the 2-D frame is displayed automatically when an exposure is completed, and the CCD is read out. Once an exposure has finished (and indeed during a subsequent run) the image displayed on the Lexidata can be extracted, calibrated and plotted using the dedicated FOS reduction software.

3.1.2 Starting up

Sit at the observer station and select a free account number from the white board behind you, say 8. A free account is an account without anyone's initials against it. Sign on with your observer identification (your initials)

*SIGNON ABC,8,8 (or si abc,8,8)

You will be given a few welcoming messages, finishing with a * as the invitation to type. Type in

*ADAM

This leads to a question/answer dialogue, the answers to which are mostly obvious. You are given the choice of storing your data on disk or tape — it is usual to store on disk in the first instance as it is possible to dump your data files to tape during subsequent runs (using FITSOUT). The Perkin Elmer 3210 instrument computer uses an Egle disk (called sys:) for all software and data storage - there is space for 500 FOS images, if the disk is relatively empty. This should be sufficient for several nights observing. The software informs you on startup how many images there is space for as it is unlikely that the disk will be completely empty of data files. If this is less than 50, contact a member of the software group, who will endeavour to tidy the disk and give you more space. If you have filled the disk with your own files, then use PURGE to delete files you have already written to tape. It is worth giving a word of warning here; it has happened that the Egle disk crashed losing the observer's data, hence it is a good idea to dump your data to tape every couple of hours or so. After five minutes or so, you will get the prompt

ADAM>

which is your invitation to type in commands in the ADAM environment. The three most important commands - after the correct A&G box and slit configuration has been set, are the WINK, GLANCE and RUN commands.

ADAM> RUN n "object comments"

Clears the CCD, opens the shutter for n seconds, closes the shutter, reads the exposure into a file SYS:FOSABC.m, where ABC is your observer id and m is the current run number, e.g. 001. The image is automatically displayed on the lexidata, erasing any previously displayed data, and the run number is updated to m+1.

ADAM> GLANCE n

Clears the CCD, opens the shutter for n seconds, closes the shutter, reads the exposure into a file SYS:FOSABC.000. The image is automatically displayed on the lexidata, erasing any previously displayed image, It will be overwritten by any subsequent GLANCE. If you decide you want to keep the GLANCE exposure, then you can do so by issuing the ADAM command

ADAM> KEEP "object name"

which copies the GLANCE file into the next file number.

A standard GLANCE includes the collection of FITS packets, So for a GLANCE of less than about 30 seconds, there is an overhead, while these are being collected. If the GLANCE is just a test exposure, without any likelihood of being saved, use WINK.

ADAM> WINK n

Operates in an identical fashion to a GLANCE command, except no FITS headers are collected for the output file. It will be overwritten by any subsequent WINK. If you decide you want to keep the WINK exposure, then you can do so by issuing the ADAM command

ADAM> KEEP "object name"

which copies the WINK into the next run number. The collection of FITS headers is done at the stage of the KEEP.

One major difference between the GLANCE, WINK and RUN commands is that GLANCE and WINK always runs as foreground tasks, tying up the terminal, but a RUN of more than 10 seconds runs as a background task, freeing the ADAM terminal so you can manipulate a previous image, write data to tape etc. However, if you do decide to use the terminal during a RUN, it is advisable to make sure you finish before the RUN does. A warning is given 30 seconds before chip readout comences.

Two other frequently used commands governing runs are ABORT and TIME, the former stopping an exposure without creating an output file, the latter amending the exposure time. A manual of all CCD commands is kept in the INT control room.

3.1.3 Preparing for observing

Earlier we discussed the absence of any need for lengthy set up procedures—a few checks as indicated in section 2.1 will reassure the observer. Directly the sky is dark enough, the night assistant will acquire a bright star, and SNAFU (calibrate out the pointing error) onto the centre of the IDS slit. He will then focus the telescope, thereafter the focus will track automatically as the temperature changes.

3.1.4 FOS observing modes

By now you should have decided on which of the 4 possible FOS observing modes to use. These modes are selected by selecting a dekker and field lens configuration via the commands

ADAM> DEKKER M

ADAM> BSCF N

See appendix A for details of the different choices.

It is straightforward to change between these modes, so you can change as often as necessary during a night to suit your requirements. The 4 modes are:

Mode A: Beam switching point sources with 5", 2", or 1.2" slots, 12" apart both orders

Mode B: Beam switching extended objects with 25"slots, 85" apart, both orders

Mode C: Long slit, 200" slot, first order only

Mode D: Single object, 25" slot , both orders.

The format of the data taken in these modes is shown in appendix A figure A.1. Choosing between the modes depends on a variety of factors and personal preferences. The most commonly used modes of observing are Modes C and D.

3.1.4.1 Beam switching or not?

This is a useful facility for eliminating flatfield uncertainties. Each observation consists of a pair of exposures, I and II, taken in each of the 2 apertures, L and R. Sky subtraction can be performed via (L-R)I + (R-L)II, and the result is a 2-D sky subtracted frame, which is very useful for extended objects.

Mode A gives a 5" or less slot, which is rather small. Mode B gives a 25" slot, which is well suited to work of this nature, but unfortunately the apertures are 85" apart. This means that the TV cannot see both apertures simultaneously.

For faint object work, where a single 1-D spectra is the required final product, these modes could still be used. Modes C and D are more appropriate particularly since the online software is designed to handle these modes more effectively.

Mode C is a 200" longslit mode used for multiobject work, and very extended objects.

Mode D is a centralised 25" slot offering enough local sky for interpolative sky subtraction. Flatfielding is required.

3.1.4.2 Second order or not?

FOS offers two (and possibly three) orders on a cross dispersed format. First order covers the region 5170Å to 10830Å, second order covers 3400Å to 5670Å and third order approximately 3400Å to 3780Å. The short wavelength cutoff is governed by the ultraviolet edge of the glass components in the FOS optics. In modes A B and D both orders can be taken simultaneously. In mode C (long slit) clearly it gets rather confusing, since the second order signal lies on top of the sky from the first order. If there are several objects you must be careful that the spectra do not overlap. On the other hand the software will do its best to subtract any adjacent signal, so there may be occasions when long slit, two order mode is acceptable, although it is not to be recommended.

The sensitivity of FOS in the second order is now extremely good, since the installation of the blue coated GEC CCD in May 1988. Second order resolution is twice as good as first order, and so narrow features show up more easily than in first order.

Some third order response is now evident, but little work has been done on calibrating it.

The full chip modes B and C require a field lens in the below slit colour filter slide to avoid vignetting. To kill second order insert a GG495 field lens. To keep both orders insert the clear field lens. A copper sulphate filter is also available in the below slit neutral density slide. This preserves second order but destroys first order longwards of about 6000Å. It is useful for multiobject work in second order.

3.1.4.3 Switching Modes

Switching between modes can easily be done via ADAM procedures, or by typing in a string of ADAM commands. For example

```
ADAM> Procedure longslit
Proc> Dekker 0                 long slit
Proc> bscf 1                   clear field lens
Proc> end proc
ADAM>
```

sets up a command procedure called longslit, which is all you now have to type to go to that mode. Procedures can be stored in a file by issuing the command

```
ADAM> put myproc
```

and called back again for use on future nights with the command

```
ADAM> get myproc
```

Don't do this during a run though; you will get the message
ADAM ERROR: all procs aborted Dictionary being got from MYPROC.DCT
Do not panic. Nothing has happened. Executing a GET during an exposure is forbidden by the software as it would corrupt the run. Wait until the run is complete and repeat the command.

3.1.5 Other variables

The only other variables you can change with FOS are the slit width and the A&G facilities (lamps,mirrors, above slit filters.) These are exactly as for the IDS and the MIMIC display will correctly show their current status.

3.1.6 Other considerations

FOS slightly undersamples its spectrum. 1 GEC pixel (22 micron= 10.7Å in first order) is equivalent to 1.3 arcsec at the slit. The optimum resolution for a narrow slit is observed to be 1.15 pixels fwhm. In principle to match a 2 pixel fwhm requires a 2.1 arcsec slit, but the resolution is then approximately 21Å fwhm. Narrower slits will produce sharper features which is generally desirable, since 21Å resolution is often inadequate for absorption line work. The online software does not resample the spectrum, so this is an important point. In good seeing, a 1.0 arcsec slit gives 15Å resolution.

With such a wide spectral coverage, another important factor which is affected by the slit width is light loss due to atmospheric dispersion. There are two ways to overcome this problem:

1) align the slit along the parallactic angle - this is shown on the telescope status screen, or

2) widen your slit to compensate. As a guide, the following displacements occur across the orders of FOS at various zenith distances,

	Displacement (arcsec)	
z.d.	1st order	2nd order
(deg)	(0.5-1.0micron)	(0.4-0.55micron)
30	0.61	0.64
45	1.05	1.10
60	1.82	1.90
75	3.92	4.10

3.1.7 File Allocations

Various sorts of files are used to help the user in his data analysis. These have the following shorthand notations

Rm	for SYS:FOSABC.m	run files
Sm	for SYS:FOSSTO.m	store files
Tm	for SYS:FOSTMP.m	temporary files

Store files can be used for reduced data, temporary files for intermediate steps in the data reduction. For example, to display run 6 on the lexidata, simply type

ADAM> DISP R6

In addition, many ADAM procedures adopt the convention of a current image, which by default is the last image called (it could be a GLANCE image or the latest RUN image).

3.1.8 Data acquisition

We are now ready to start observing. The target object has been acquired and put on the slit, and a guide star found. We start taking data with

ADAM> RUN 1000 "target 1234 1000s"

The cosmic ray rate is typically 20-30 events per full CCD frame per 1000 seconds. These can be weeded out of the sky areas by the reduction software, but if they land on the object spectrum you can only clean them out by comparing with another exposure. For this reason, it is best to limit exposures to less than 1800 seconds. There is an overhead of about 30 seconds while the chip is read out and the image displayed before you can issue another RUN command. As the sky alone generates between 200 and 1000 adus per pixel per 1000 seconds, FOS is mostly well above the readout noise problems in typical exposure times.

All of the normal CCD commands are applicable to FOS, and so the observer is referred to the CCD userguide, which is kept in the INT control room.

Chapter 4

Data Analysis

4.1 Data Reduction

4.1.1 Introduction

FOS reduction is essentially a two stage process at the moment. The initial stage, as a quick look at the data, is undertaken on the Perkin Elmer instrument computer, and handles object extraction and wavelength calibration. The full FOS reduction package has been rewritten and runs on the main Vax data reduction computers. Details may be found in the WHT FOS userguide. Alternatively it is possible to reduce FOS data using standard packages such as FIGARO, which for many users is the preferred option.

The aims of the FOS on-line reduction package are to provide

1) fully reduced and calibrated spectra so you can see what your data represent.

2) facilities for interactive classification and redshift determination.

The steps taken to fulfill 1) are easily completed in a few hundred seconds, enabling the observer to do so while the next exposure is in progress. The following points should be noted :

1) Modes A and B (beamswitching) do not have their own dedicated software, but can be reduced using some of the standard CCD arithmetic routines in conjunction with the FOS software.

2) Default wavelength and flux calibration is provided. The former should not worry the observer who can easily take comparison lamp exposures to check the calibration. The latter however, is not able to take account of variations in extinction, and so it is recommended that standard stars are observed for this purpose.

Following the upgrade of FOS in May 1988, considerable changes were made to the software, most of which will be invisible to the observer (except that now the routines work properly). The most obvious external change is that the FOS chip is displayed left to right across the Lexidata rather than up and down This means the full 590 rows are now visible, rather than only 512. The display is such that the longest wavelengths are to the right. The following routines have been modified, as it was found they did not always handle the arithmetic correctly:

NITPICK
FOSCOFS
TRIM
SPECTRUM
SPECPLOT
COMBINE
SLICE

The following routines have been removed:

FADD	use ADD it is more general
CONVERT	use CHFORM it is more general
EXTRIC	use TRIM and LEXEXT
FDIV	this was never available
OFG	this was never available
ABSCORR	this was never available

The following routines are original:

DCSUB
DOFF
FFNORM
FMULT
VIEW
ZAPCOLS
ZED

For the sake of completeness, several stages of on-line data reduction are described which are rarely ever used, as all that is necessary usually is to extract the spectrum and wavelength calibrate it. The stages which can easily be ignored are *Defect removal, Cosmic ray removal, and Flatfielding.* So unless you really want to use these facilities, skip on to *Spectrum extraction and Sky subtraction.*

4.1.2 Defect removal

ZAPCOLS allows the user to remove column defects. The program prompts for the first and last column numbers that define the area to be zapped. This area is then replaced by the mean of the two bordering columns. See Appendix C for details of the current chip defects. A negative number terminates the prompts. Routine defect removal should be unnecessary because the sky subtraction algorithm rejects anomalous pixel values in the sky regions, and of course the observer should take care to see the object spectrum does not land on a defect. Luckily there are very few on the chip currently used in FOS.

4.1.3 Cosmic ray removal

NITPICK compares two frames, and identifies features which are more than a specified significance level away from the value in one and replaces these pixel values with the corresponding values from the other. Photon noise is automatically allowed for, using known CCD statistics. Sky subtraction software automatically allows for cosmic ray removal, so this is only run if the object spectrum is affected. NITPICK only corrects one frame, so you have to apply the first frame vs the second, and then the second frame vs the first to correct both frames.

As a general guide, 4 sigma is a good starting level. Care should be taken not to try to remove too many small variations. NITPICK produces a map of which pixels have been affected. This image should be displayed; if you don't and there is a shift between the two images you are comparing, you will be unaware that part of your spectrum has been cleaned away.

4.1.4 Flatfielding

FOS has its own standard flatfield which observers should be able to use and take home with them. Most observers do like to take their own however. Use a slit width similar to that used for your observations, and expose the tungsten lamp, taking care not to saturate. Use the GG495 filter for first order, take several flatfields, use COMBINE to produce an average flatfield, then use DCSUB to remove the bias from this image. finally use FFNORM to remove the strong wavelength dependence. This produces an image which has exactly 20000 counts where no light fell, and an average of 20000 counts where light fell, independent of wavelength.

To apply a flatfield, use DOFF which automatically removes the dc bias, and handles the 20000 count normalisation.

4.1.5 Spectrum extraction and Sky subtraction.

Normally this is the only part of the online reduction package used by observers. The heart of the FOS reduction software is contained in these routines. Each spectral order presents a curvature which depends primarily on the FOS optics but also on the atmospheric dispersion when the slit is near the parallactic angle. The curvature can be mapped at any z.d. as a high order polynomial fit to an observation of a bright point source. using the routine FOSCOFFS. The typical observer, working at reasonable z.d. will not have to worry about this and can use the default calibration.

The first step is to straighten the separate orders of the spectrum, one at a time. TRIM prompts you for the order you want to straighten, and then using the lexidata joystick to delimit this area, straightens the spectrum using the coefficients stored in frstcofs.dat and scndcofs.dat depending on which order you are working on. Straightening the data reconfigures the pixels according to the curvature coefficients, but there is no resampling. If the observer displays the TRIMmed image each new y value represents a single spatial point along the slit.

The next step is to carry out the sky subtraction. This is done using the routine SPECTRUM. You enter 4 cursor positions using the Lexidata joystick and control buttons. Depending on how you select your sky area(s), SPECTRUM will either interpolate under the object or calculate a straight mean. If you don't select any sky areas, the object area will not be sky subtracted.

The resulting spectra from TRIM and SPECTRUM are of a standard form — a spectrum pair consisting of the sky subtracted object signal, and the sky spectrum along the slit. The wavelength to channel number relationship is very nearly linear, and so there is no need to resample the reduced spectra.

4.1.6 Flux calibration

Data are flux calibrated by multiplying by the default flux calibration files referred to by logical names cal1 and cal2, there is no flux calibration for third order at present. Use FMULT, and you will have relative fluxes at the base of the earth's atmosphere. Fluxing is to be recommended, as it makes it easier to recognise features in the raw spectrum at wavelengths where the CCD sensitivity is falling off. It must be made clear though, that there is no substitute for taking observations of standard stars, and fluxing your data using the routines contained in say FIGARO. To get absolute fluxes, account must be made of atmospheric extinction; LPO Technical Note 31 details how to do this.

4.1.7 Plotting data

SPECPLOT will now plot your data (object spectrum, or object and sky) on the lexidata with sensible wavelength limits, with and without autoscaling. The wavelength calibration is via two ADAM variables, defining channel 0, and the wavelength interval per bin. Once the plot is complete, you can use the Lexidata cursor to mark features in the spectrum you might be interested in. The wavelength of the feature is written both to the Lexidata, and to the ADAM terminal. Use LEXPLOT if you want a hard copy on the line printer.

Useful procedures for quick FOS data reduction were written by Andy Lawrence and his team in May 1989, and are reproduced in Appendix D. In its most automated mode, a plot of a single object was produced in 1 min 58 secs from issuing the command to execute the procedure.

Again, it must be emphasised that there is no substitute for doing a rigorous reduction away from the telescope; the on-line reduction facilities are meant to enable the observer identify the spectrum with ease. To get the best from the data, use should be made of optimal extraction techniques (this is after all a Faint Object Spectrograph). Various reduction packages do already have such facilities.

Appendix A

Field Lenses, Dekkers, and Observing Modes

A.1 Field Lenses

Field lenses Below slit colour filter slide (upper of pair)

Position	Action	Use
BSCF 0	Clear no lens	Mode D,A(both orders)
BSCF 1	Clear field lens	Mode B(both orders)
BSCF 2	Yellow field lens	Mode C(1st order only)

A.2 Filters

Filters Below slit neutral density slide (lower of pair)

Position	Action	Use
BSND 0	Clear	Most of the time
BSND 1	$CuS0_4$	Mode C(2nd order only)

A.3 Dekkers

Position	Action	Use
	Clear	Long Slit mode C
1	25 arcsec slot	Short slit mode D
2	2x25 arcsec slot	Short slit mode B
3	1.2 arcsec slot	Set up
4	Occulting	
5	Occulting	
6	2x1.2 arcsec slot	Short slit mode A
7	2x2.0 arcsec slot	Short slit mode A
8	2x5.0 arcsec slot	Short slit mode A

Figure A.1: The FOS dekker

Appendix B

FOS Commands and Calibrations

B.1 Glossary of on-line commands

Here is a list of commands you will find useful for operating FOS. It includes some commands in common with the CCD on the IDS and A&G box. For further details see the folder containing a list of commands for all modes of operation which is kept in the INT control room.

Command	Parameters	Description
1la(mp)	on/off	lamp 1
2la(mp)	on/off	lamp 2
Abo(rt)		Abort a run
Afa(rc)	n	select A arc filter
Asn(d)	n	select above slit neutral density filter
Bfa(rc)	n	select B arc filter
Bsc(f)	n	select below slit field lens
Bsn(d)	n	select CuS04 filter
Comp(mirror)	in/out	comparison lamp mirror
Centre	tv/gd	tv/guide probe on axis
Chform		change image data format
Combine	respond to prompts	average many exposures
Continue		continue a paused run
Dat(a)	d/t/n	redefine dump device
Dcsub	in/out	subtract dc offset
Dek(ker)	n	select dekker position
Disp(lay)	Rn	display run n

Command	Parameters	Description
Doff	in ff out	applies flatfield
Ffno(rm)	in out	normalises to unit count
Fitsdir	respond to prompts	list contents of FITS tape
Fitsin	respond to prompts	read FITS file from tape to disk
Fitsinit	respond to prompts	initialises FITS tape
Fitsout	respond to prompts	writes fits image from disk to tape
Fli(pmirror)	in/out	flip mirror for tv viewing
Fmult	in1 in2 out	multiply images preserving descriptor of in1
Fosc(ofs)	respond to prompts	set up curvature polynomial files
Fosp(lot)	respond to prompts	interactive lexidata plotting
Gdx(y)	x,y	move guide probe
Gla(nce)	secs	perform glance run
Hartc(los)	a/b	closes hartmann shutter(s)
Harto(pen)	a/b	open hartmann shutter(s)
Hstat		status of hartmann shutters
Iop(roceed)	0/1	wait/not wait for command completion
Keep	object	save glance run as Run file
Lexplot	respond to prompts	hardcopy of lexidata screen
Man(ic)	respond to prompts	create subarrays
Mstat		status of FOS motormicrometers
Nd	n	comparison beam nd filters
Nextr(un)	n	set next run number
Nitpick	in1 in2 out	compares frames for cosmic rays
Pa(use)		pause an active run
Photo(m)	defaulted	photometry/inspection program
Proc(edure)	name	create an Adam procedure
Ru(n)	secs "title"	perform a standard run
Runstat(us)		check run status
Shutdown		shutdown Adam and instrument safely
Slice	respond to prompts	centroids and profile program
Slit(jaw)	n	set slitwidth in microns
Spectrum	respond to prompts	interactive sky subtraction
Tel(e)		check CCD telemetry
Time	n	change exposure time to n secs
Trim	respond to prompts	interactive straightening of FOS image
Tung(sten)	on/off	tungsten lamp
Tvx(y)	x,y	move tv probe
Unz(oom)		unzoom Lexidata
View	respond to prompts	print pixel map on Printronix
Wink	n	glance n seconds without fits headers
Zapc(ols)	respond to prompts	remove defective ccd columns
Zed	respond to prompts	redshift feature files
Zoom	respond to prompts	zoom Lexidata

B.2 Default Calibrations

FOS has several default calibration files. These are listed here for reference. If you overwrite them, please reset them for the next user.

Curvature coefficients

These are stored in the files:

Obs:frstcofs.dat (first order)

Obs:scndcofs.dat (second order).

The coefficients were carefully determined via observations of many standard stars and should be adequate for general use at low and moderate zenith distances.

B.3 Flux calibration

The default relative flux calibration files are:

Obs:foscal1/g (first order)

Obs:foscal2/g (second order)

Logical names CAL1 and CAL2 can be used in place of these filenames. Divide your data by these to flux calibrate it.

Appendix C

Characteristics of the FOS CCD

Prior to May, 1988 an uncoated GEC P8603C CCD had been used in FOS. In May, 1988 a new blue sensitive GEC P8603C CCD was installed. This chip is extremely clean, with no defects at normal operating temperature, and an extremely good blue response. There is one hot column which appears at 20deg above operating temperature.

C.1 CCD Format

Figure C.1 shows the CCD format; in particular the position of the imaging area within the data frame. This figure shows the appearance of the CCD as displayed on the Lexidata, which is a mirror image of the actual chip.

The CCD is mounted with its long axis in the dispersion direction. Row 1 is read out first, and appears at the right of the Lexidata screen. Row 1 is the red end of the spectrum.

Columns 1–12 are the 'underscan' region of the CCD, that is, it is an area not subject to illumination during an exposure. This region can be used to determine the zero reference level for the data frame. This is typically 123 $\pm$ 7 adu.

Columns 13–397, and rows 1–578 are the true image elements of the CCD.

Columns 398–400 and rows 579–590 are the overscan regions. They contain residual signal, the magnitude of which is indicative of poor charge transfer efficiency.

C.2 Signal level calibration and readout noise

The CCD signal charge is converted to a voltage, then amplified and digitised to 16 bits. The computer measures the signal as an analogue-to-digital conversion unit (ADU). In the present configuration,

1 ADU = 0.95 electrons.

The readout of any signal charge from a pixel has an intrinsic signal independent electrical noise introduced by the output circuitry of the CCD (readout noise). for the current CCD:

Readout noise sigma = 7 adu = 7 electrons r.m.s.

The measurement of readout noise on an erase (bias) frame, that is a frame of zero exposure, is a useful test of whether the CCD camera is working as expected. Photom/stats should reveal a mean background level of 123 adu with a sigma of 7.

The current CCD has a potential well charge of 65535 electrons. Linearity is good up to 40000 electrons with no problems. Exposures are therefore okay up to 40000 adu.

C.3 Other features of operation

The CCD is run at a stabilised temperature of 150K. This temperature was chosen for optimum overall performance taking into account dark current, readout noise and charge transfer efficiency.

At least two hours should be allowed before serious observations are made following the switch-on of the CCD camera. This is because of a charge injection effect that is apparent for the first few hours of operation after power up and which is observed as an excessive dark current count.

The cosmic ray detection rate is approximately 15 events/1000 seconds over the whole chip.

C.4 Position of focus in the camera

The camera was focussed in May 1988 after the installation of the new blue sensitive GEC CCD, the position of which is not expected to move by very much. To check the focus, run MSTAT from the Adam terminal, which should give the following values for the relevant parameters:

s	r	b	f	ha	va
378	481	291	383	95	2

The values obtained using MSTAT should be within 10 units of these.

Figure C.1: CCD format

Appendix D

FOS reduction procedures

D.1 Useful Procedures for Quick FOS Reduction

In May 1989, Andy Lawrence wrote a set of procedures to automate the TRIM, SPECTRUM, SPECPLOT and LEXPLOT routines which are used to reduce the FOS data at the telescope, so that a first order spectrum was produced in about the time it took to acquire the next object.

Because of ADAM niceties about character strings, and the fact that R1,S1,T1 etc. are psuedo-variables standing for the real file name,(e.g. R1 is SYS:FOSABC.001, where ABC is the observer's signon initials) it is not obvious how to put RUN numbers into procedures. The following (in which parameter names are arbitrary) will serve as a starting point.

To reduce the FIRST order spectrum from the raw image and output a 1D spectrum :-

```
ADAM> Procedure RED inim outim          See notes
Proc> DECLARE inim CHAR 20
Proc> DECLARE outim CHAR 20
Proc> TRIM inim FIRST NO T1             See notes
Proc> DISP T1                           Displays straightened first order
Proc> SPECTRUM T1 outim YES             Prompts for star and sky positions
Proc> End proc
ADAM>
```

Note:-

a) Do not use previously defined ADAM variables (e.g. 'in' and 'out' are used by the COMPMIRROR command).

b) For well exposed spectra taken using the FOS dekker in position 1, (24 arc seconds, single aperture) TRIM will work well in the automatic mode, and find the dekker edge itself.

```
ADAM> put RED                            (Saves RED for next time).
```

You can reduce R1 and put the spectrum in S1 by typing:-

```
ADAM>RED R1 S1
```

To plot the spectrum on the LEXIDATA and measure wavelengths on it, use the following procedure:-

```
ADAM>Proc LOOK spec sca
Proc>DECLARE spec CHAR 20
Proc>DECLARE sca
Proc>SPECPLOT spec LEX 5400 8000 1 1 sca 0   (See notes).
Proc>End Proc
ADAM>
```

Note:-

a)5400 and 8000 in this line are the minimum and maximum wavelengths,which you can adjust to suit your requirements

b)SPECPLOT will insist on prompting for a title and comments, but will accept carriage return as null.

c)The scale should be about int(maxcounts/1000). Maximum counts are output to the screen by SPECTRUM (and hence by procedure RED).

You can invoke this with:-

```
ADAM>LOOK S1 6
```

In addition to the lexidata display, you can get a hard copy on the line printer.

```
ADAM>Proc HLOOK sp sc                 (See note.)
Proc>DECLARE sp CHAR 20
Proc>DECLARE sc
Proc>LOOK sp sc                       (Assumes you have Proc LOOK)
Proc>LEXPLOT                          (Dumps LEXIDATA to Printer)
Proc>End Proc
ADAM>
```

Note:-

a) Variable names must not be duplicated in your various procedures.

If you are feeling really ambitious, you can do everything from the raw image to the hardplot of the spectrum in one fell swoop.

```
ADAM>Proc AUTO raw final
Proc>DECLARE raw CHAR 20
Proc>DECLARE final CHAR 20
Proc>RED raw final                    (Assuming you have Proc RED)
Proc>HLOOK final 0                    (See note.)
Proc>End Proc
ADAM>
```

Note:-

a) The '0' is the scale for the plot, and is a way of overcoming not knowing the maximum counts from the start, and will force a prompt.

In tests with one object in the slit, and measuring one wavelength from the SPECPLOT stage, the procedure AUTO took fractionally under 2 minutes from starting, to returning to the ADAM prompt.

Run it by typing:-

ADAM>AUTO R2 S2.

Remember to answer the few remaining prompts!