Chapter 2

The Danish Faint Object Spectrograph and Camera

The Danish Faint Object Spectrograph and Camera (DFOSC) is a focal reducer type of instrument. It provides the possibility of doing wide field imaging (13 by 13 arcminutes field of view) and of doing low resolution grism spectroscopy with a wide selection of grisms with resolution between 1.2Åand 20Å. The highest resolution of about 4300 (1.2Å) is achieved in the optional echelle mode. In the future a Multi Object Spectroscopy (MOS) mode will also be made available. The instrument was designed by Copenhagen University Observatory in collaboration with ESO and built by Copenhagen University Observatory.

The beam from the telescope passes through the FASU where two filter wheels in the converging beam allows narrow and wide band filters to be mounted. The unvignetted field is achieved with 80mm minimum diameter filters. After the beam has passed the FASU it focusses on the aperture plates in the aperture wheel where various slits can be mounted. The light passing through the slit continues through the collimator to form a parallel beam which passes the filter wheel and grism wheel before it is imaged by the camera on the CCD. All the DFOSC wheels have 8 positions of which 7 can be used for optical components and the 8'th position is a free position. The minimum unvignetting diameter for filters mounted within DFOSC is about 45mm.

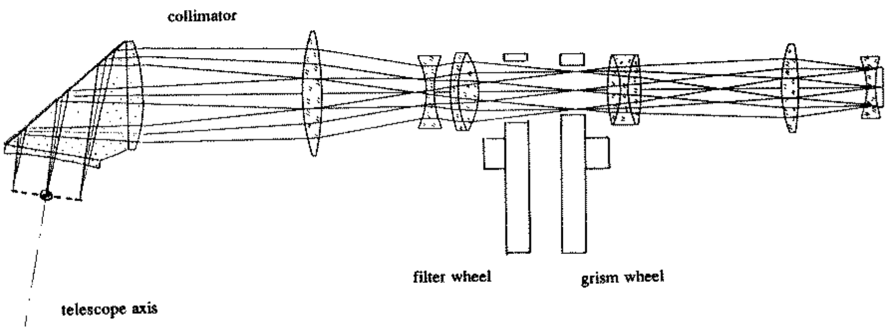

Figure 2.1: Optical layout of DFOSC

Table 2.1: DFOSC optical characteristics

Collimator focal length	252.2mm
Collimator linear field	52.9×52.9mm
Camera focal length	146.3mm
Camera linear field	30.7×30.7mm
Reduction ratio	0.58
On the Danish 1.54m (nominal values)	
Input f-number	8.6
Output f-number	5.0
Input scale	64.2 μm/"
Output scale	37.2 μm/"
Field of view	13.7×13.7 arcmin

The basic optical characteristics of DFOSC are summarized in Table.2.1.

2.1 The Loral CCD, Image Orientation and Field of View

The CCD currently in use with DFOSC is a backside illuminated LORAL/LESSER chip with 2052×2052 pixels provided by the Copenhagen University Observatory. The pixel size is 15 μm. The readout time for a full frame is 1min 15sec. The CCD is operated at a temperature of $-100°$C. There are two output amplifiers, labeled A and B which can be operated in both high and low gain. The B amplifier is the default as it has the most stable bias level with respect to detector temperature and it is usually operated in high gain mode to achieve the lowest read-out noise.

The CCD is controlled by the BROCAM CCD controller which is interfaced to a Linux PC on which the Brorfelde Image Aquisition System (BIAS) is running. This PC contains a memory buffer card which recieves the image directly from the CCD controller and the BIAS stores the image locally on the PC hard disk and remotely on the MIDAS workstation.

Table 2.2: CCD parameters for the LORAL/LESSER W11-4 chip

Amplifier	gain	Conversion factor	RON	linear limit	linear limit	bias/temp. slope
A	high	1.31	6.9	135000	65535	4.7
A	low	2.94	8.7	135000	45000	4.7
B*	high	1.31	7.2	125000	65535	2.5
B	low	2.85	8.4	125000	40000	2.5
		e^-/ADU	e^-	e^-	ADU	ADU/K

* This is the default setup.

Bias and dark current

With the present set-up the bias level is around 490 ADU for both amplifiers, with a slight gradient of about 3 ADU in the horizontal direction. The dark current is approximately 2.5 e^-/pixel/hour at

$-100°$C.

Beware that the bias level is temperature sensitive, and might drift a few ADU even when the displayed CCD temperature is within a degree from the operating temperature. The effect is hard to monitor as the chip currently does not provide an overscan region. The laboratory values of this dependence (valid between $-90°$C and $-101°$C) is noted in table 2.2 as the slope of the best fitting linear relation. Note that amplifier A is significantly more sensitive in this regard. It is thus recommended to take several bias frames during the night if you are working with very low background levels especially if the ambient temperature is changing significantly.

Currently the CCD is only offered in an un-flooded state as the flooding procedure has not proved reliable and stable yet. The danish CCD team is working hard on improving the situation.

2.1.1 Limited field of view

Mounted on DFOSC, the LORAL/LESSER CCD covers a field of 13.3×13.3 arcminutes, with a pixel scale of 0.39 ″/pxl. The images appear on both SAOIMAGE and in MIDAS with north up and east to the left. Note that amplifier A gives a mirrored image, with East replacing West and vice versa. This has serious implications for the `point` batch as it does not support this orientation yet.

If filters are mounted in the adapter (FASU) rather than within DFOSC, then part of the field will be obscured if the filters are 60mm diameter filters. Even with 60mm filters in DFOSC there appear to be vignetting within DFOSC, but in reality this is a strong decrease in the quantum efficiency towards the edges of the un-flooded CCD. The light loss is about 60% in the R filter at the very edge of an image, and more or less linearly goes to 0% 400 pixels from the edge. It flatfields perfectly, but the noise is higher in the regions with less signal. High precision photometry should be made within the central 1250×1250 pixels.

2.2 Imaging

DFOSC offers the possibility of doing photometric observations of a big field in the sky, but the size of the field comes of course at a price. The limitations comes from the fact that the light has to pass several optical components on its way to the detector.

2.2.1 Image quality

The image quality is well matched to the current capabilities of the Danish 1.54m telescope, and FWHM down to 0.8" have been reported. The distortion is also reported to be 0.5% in the corners of the field, i.e. 9' from the center of the field.

2.2.2 Sky concentration and flat fielding

As most focal reducers DFOSC is also affected by the so-called "sky concentration". It is an effect that makes it more difficult to produce really good flatfields because scattered light preferentially is directed towards the center part of the field by the optics. This causes a distortion of the flat field which will lead to an underestimate of the counts in the central part of the field. For DFOSC the effect has been measured at the 2% level. This is however comparable to the accuracy with which normal flat fields can be obtained. If higher accuracy is needed a more sofisticated procedure has to be followed, see f.ex. Andersen et al. (1995).

2.2.3 Narrow band imaging

Narrow band filters should NOT go into DFOSC itself but rather in the FASU. As the filterwheel in FASU is located in the parallel beam the light from sources in different positions in the field of view will pass the filter at different angles. For this reason the central wavelength of the filter will change slightly accross the field. For broad band imaging this is no serious concern, but for narrow band imaging this can be very critical. Mounting the filters within the FASU places the filter in the converging beam where the light for all objects in the field enters the filter in more or less the same way and thus circumvents the problem in the parallel beam.

(Explain and give formula so people can estimate the effect for themselves)

Please note that the position of the filter wheels in FASU are NOT recorded in the image headers. So you will have to keep track of the position yourself.

2.2.4 Broad band imaging

The current set of broad band filters (Bessel UBVR and Gunn i) are only 48mm in diameter and will introduce significant vignetting when mounted in the FASU. For this reason it is important that they are mounted in the DFOSC filter wheel. Furthermore the position and content of the filter wheel in DFOSC is recorded in the image header.

Approximate count rates in BVR and I were measured in Dec.95 based on 14-18 stars in the field SA98. The CCD was the BroCam thinned Loral CCD W11-4 without UV-flooding. The resulting count rates for a 15'th magnitude star with zero color are given in Table.2.3.

Table 2.3: Count rates in BVRI for 15'th mag object

Filter	Count rate
B	780
V	1950
R	2390
I	1170
	e−/sec

No correction for extinction has been included, but the airmass was only about 1.15 for these measurements.

A set of simple equations for evaluating on-line magnitudes were also derived:

$$B - b \quad = \quad 0.24(\pm 0.05) \times (b - v) + 22.01(\pm 0.07) \qquad (2.1)$$

$$V - v = 0.06(\pm 0.01) \times (b - v) + 23.16(\pm 0.02) \quad (2.2)$$
$$R - r = 0.10(\pm 0.04) \times (v - r) + 23.42(\pm 0.03) \quad (2.3)$$
$$I - i = 0.06(\pm 0.02) \times (v - i) + 22.70(\pm 0.02) \quad (2.4)$$

Here the lower case letters refer to instrumental magnitudes computed on the basis of the number of electrons/seconds detected from the object.

Note the strong color term in the B-band. This is most probably due to the rapid fall-off of the quantum efficiency of the CCD towards the blue.

2.2.5 Shutter timing

The shutter timing is adjustable in the BIAS program and the delay (of 0.11 sec) has been largely eliminated and is now of the order a 0.01sec. However there might still be a dependence on temperature as well as on orientation of the telescope and instrument. In conclusion, exposures of less than 5 seconds should be avoided for photometric purposes.

2.3 Spectroscopy

DFOSC provides a wide range of spectroscopic capabilities ranging from very low resolution long slit spectroscopy to intermediate resolution echelle spectroscopy and long slit spectroscopy. In the future a multi-object spectroscopy (MOS) capability will also be made available.

2.3.1 Slits

A new set of slit was made available in Jan.96 and the following sizes are available: 1.0, 1.5, 2.0, 2.5, 5.0, and 10.0 arcsec. The 1.0 arcsec slit is not very smooth showing flux variations of $\pm 5\%$ along the slit. Due to the flexure and limited offset accuracy of the telescope the use of a 1.0 arcsec slit is difficult. Furthermore it is often not very efficient considering that the seeing is often worse than 1.0 arcsec. Thus, the narrow slit is only recommendable when the highest possible resolution is required and some loss in efficiency can be tolerated.

For use in echelle mode a special set of slits is available which only have a slit length of about 10 arcsec to prevent the echelle orders to overlap.

2.3.2 DFOSC grisms

DFOSC is equipped with a large set of grisms. In resolving product they range from ≈ 200 to ≈ 4000 and in each resolution domain blue, visual and red grisms are available. The choice of a blue or red grism not only improves the efficiency but also allows the user to avoid second order contamination in the red region if this is the region of interest.

The grisms #9 and #13 are echelle grisms and the grisms #10, #11 and #12 can be used as cross dispersers, in which case they should be mounted in the DFOSC filterwheel.

Table 2.4: Grism characteristics

Grism#	λ_c	λ_{blaze}	Grooves/mm	Dispersion	Resolving product[a]	$\Delta\lambda$	Range
3	390	430	400	17	690	0.55	330-640
4	480	580	300	22	700	0.83	350-700
5*	650	700	300	22	870	0.75	520-1020
6	390	400	600	11	990	0.39	320-550
7	530	525	600	11	1300	0.41	380-680
8	650	700	600	8.8	2200	0.30	580-830
9[b]			79	2.6	4300	0.12	330-1100
10	380	390	150	46	230	1.7	330-640
11	520	500	200	34	390	1.3	390-760
12	730	700	75	91	200	3.7	520-1020
13[b]	510	525	316	3.6	4200	0.12	480-580[c]
	nm	nm		nm/mm		nm	nm

[a] The resolving power is computed for an 1" slit.
[b] Grism #9 and #13 are echelle grisms
[c] This range is achieved using a special order sorter filter
* Grism #5 is currently being remanufactured and will only be available later in 1996.

With the current setup of the CCD, the red part of the spectrum appear in the lower part of the image, and for echelle applications the red is also to the right.

2.3.3 Echelle Spectroscopy

DFOSC offers the possibility to do intermediate resolution spectroscopy (R $\approx$ 4000) covering a large spectral range using one of the two echelle grisms (#9 and #13) and using one of the low resolutions grisms (#10, #11, and #12) as cross-disperser.

Physically this is achieved by mounting the echelle grism in the grism wheel in the normal way and mounting the cross-disperser in the filter wheel, but turned 90 degrees with respect to the normal grisms.

Grism #13 is intended for use with an order sorter filter to give intermediate resolution spectroscopy with a long slit but it can also be used with one of the order sorter grisms. Note, however, that grism #13 does not cover the full wavelength range as the individual orders are longer than the detector can accomodate (see table.2.6).

An order sorter filter is currently available to select the third order (480–580 nm).

For both grisms the efficiency falls off dramatically towards the edges of the wavelength range, as is typical for echelle spectrographs. For grism #9 the efficiency as a function of wavelength can be found in App.A.2. For grism #13 we currently do not have a tracing of the efficiency.

Table 2.5: Approximate wavelength coverage in each of the orders for grism #9.

Order	λ_{start}	λ_{end}	Order	λ_{start}	λ_{end}
6	995	1190	15	425	504
7	857	1040	16	402	475
8	754	914	17	382	450
9	675	816	18	365	427
10	611	737	19	350	408
11	560	673	20	336	390
12	517	620	21	324	374
13	481	575	22	314	360
14	451	537	23	304	347
	nm	nm		nm	nm

Table 2.6: Approximate wavelength coverage in each of the orders for grism #13.

Order	λ_{start}	λ_{end}	Order	λ_{start}	λ_{end}
2	701	862	3*	478	582
4	369	444	5	306	363
	nm	nm		nm	nm

* A special order sorter filter is available for selecting this order.

The cross-dispersers

Currently three cross-disperser are available, namely grisms #10, #11, and #12. Not only do they have different peak transmission wavelengths (400, 500 and 700 nm) making it possible to optimize the efficiency for the wavelength of interest, but they do also have very different cut-off wavelength in the blue. This means that they can be selected to avoid second order contamination in the red. The blue cut-off of grism#12, f.ex., is about 510nm and thus there will not be any second order contamination up to 1020 nm and the effective wavelength range with grism #9 will be from 530nm to 1020nm.

Echelle Wavelength Calibration

Currently we do not have much experience with the echelle mode. To determine the wavelength solution we recommend to take both ThAr and HeNe exposures. The ThAr lines might be too dense for an accurate wavelength solution but the HeNe on the other hand might not provide enough lines to calibrate all of the orders well.

For tracking the wavelength shifts during the night, the HeNe exposures should be sufficient, if a good wavelength solution has already been established. This can save some overhead as the HeNe lamps in the cover of the skybaffle are significantly smaller than for the ThAr lamp in the calibration unit.

2.3.4 Multi-Object Spectroscopy (MOS) with DFOSC

DFOSC is forseen to provide a MOS mode which might be offered to the users for period 59 i.e. from April 1997. Until then, the MOS mode is not available to general observers.

2.3.5 Fringing

As the LORAL/LESSER chip is a thinned device it suffers from significant fringing in the red. With grism#8 the amplitude of the fringes is of the order 10% and the spatial frequency is about 20 pixels (see Fig.2.2). The effect becomes really significant on the red side of 700nm. As the slit is known to move slightly with position in the sky, the fringes are suspected to move as well, making correction very difficult.

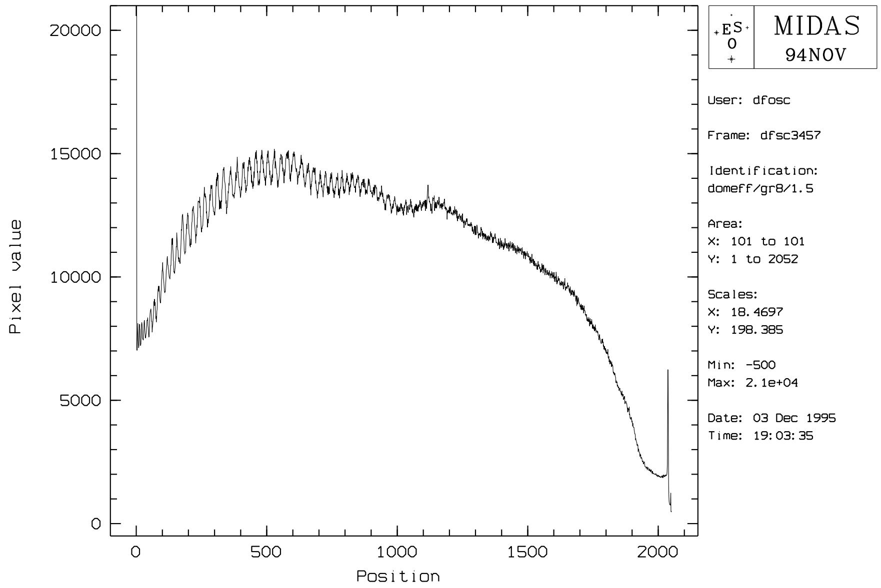

Figure 2.2: A dome flatfield with grism#8 (830-580nm).

2.3.6 Spectroscopy in the blue

The problem with most spectroscopic observations in the blue is the contamination by scattered light from the, usually, much brighter red part of the spectrum. This is true both for flat fields and for scientific observations. The effect has not yet been quantified.

TIPS:

If you are doing long integrations at high airmasses, you might consider to use a blue filter in front of the guideprobe to compensate for the differential refraction, especially if you are not able to put the slit along the parallactic angle. See App.C.

(Note that the TCS user interface does NOT show the correct identifiers of the filters! Dec.95)

2.3.7 Flexure

The flexure in DFOSC has been measured in December 1995 by measuring the position on the CCD of the image of a pinhole in the aperture wheel. The measurements were done with the BROCAM dewar

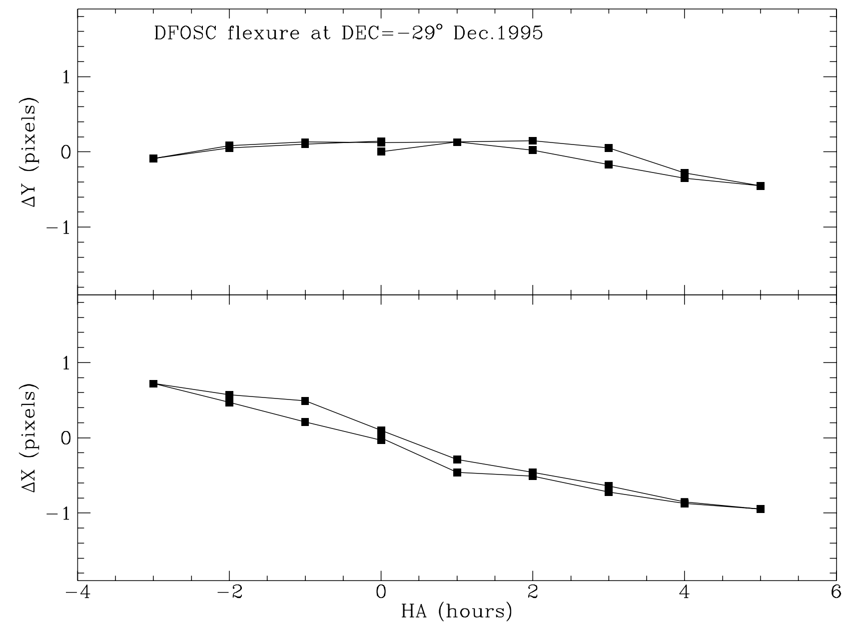

Figure 2.3: The flexure in DFOSC as a function of hour angle. The line tracks the sequence of the measurements and reveals that there is not significant hysteresis for this movement.

pointing to the south and with the telescope on the East side of the pier. In figures 2.3 and 2.4 the shift of the image in pixels has been plotted against HA and DEC respectively.

It can be seen that there is a significant movement of the slit both in the spatial direction and in the dispersion direction. Thus for obtaining accurate radial velocities it is important to acquire calibration spectra during the night in the same telescope position as used for the science exposure, if the night sky lines are not bright enough to provide the zero point offsets. the good thing is that the movement is largely elastic and there is not a significant amount of hysteresis present.

The flexure also has implications for the procedure for putting the object in the slit as the slit position can change significantly depending on the position of the telescope.

2.3.8 Calibration exposures

Wavelength calibrations

Wavelength calibrations are usually done with the He and Ne lamps mounted in the skybaffle cover. The internal calibration unit in FASU is not performing very well as the light level is much too bright and the movement of the pick-up mirror is very slow. For echelle work, however, the ThAr lamp in the calibration unit can be useful.

The calibration unit is operated from the TCS in the adapter window. The lamps in the sky baffle are switched on and off with a set of switches located on top of the computer racks in the control room, and, to be useful, it is necessary to close the skybaffle (see the TCS section in this manual for details).

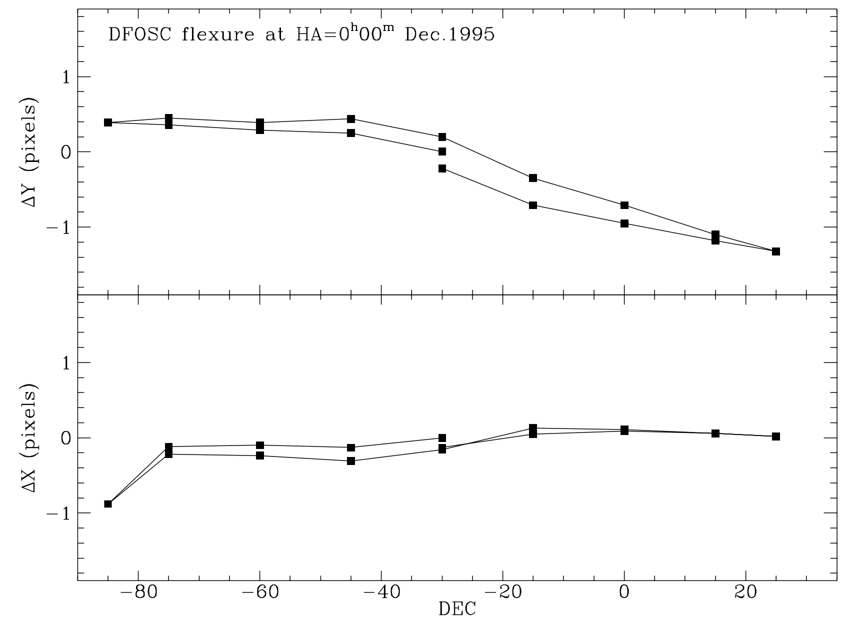

Figure 2.4: The flexure in DFOSC as a function of declination. The line tracks the sequence of measurements and reveals that there is no significant hysteresis for this movement

Typical integration times for the He and Ne lamps are of the order 10 seconds, and for the ThAr lamp in conjuction with the echelle grisms it is something similar.

In Appendix B there are a couple of examples of wavelength calibrations.

Flat fields

Spectroscopic flatfields can be obtained on the flat field screen in the dome or on some blank area on the inside of the dome using the quartz lamp for illumination. To proper calibrate variations in the width of the slit, however, it is strongly recommended to acquire twilight flat fields of the blank sky. Sky flats of this kind can also provide significantly more photons in the blue region where the quartz lamp basically gives nothing. Actually one should be careful with flatfielding in the blue as a significant fracton of the photons reaching the CCD in this spectral region might in fact be scattered red photons and thus they do not represent a true flatfield! This has not been quantified yet though.