Installation of ALFOSC at the Nordic Optical Telescope

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Abstract: In this Report I describe the installation of ALFOSC and FASU at the Nordic Optical Telescope October 13-20. A number of key features are described, among these are: flexure of the instrument, guide probe vignetting, count rates in direct imaging and in spectroscopic mode and optical quality in both direct imaging mode and in spectroscopic mode. Conclusions are given at the end of the report.

1 ALFOSC Basics

I think it would be appropriate to start this report with a brief summary of the basics of the ALFOSC instrument.

ALFOSC is a twin instrument to DFOSC on the Danish 1.54m at La Silla. Both are similar in concept to ESO's EFOSC1 and EFOSC2 instruments. That is, the instrument is a *focal reducer* consisting of a collimator and a camera. The basic function is to reduce the effective focal length of the telescope and in this way to match the pixel-size of the CCD to the seeing, resulting in a larger field on the sky for a given CCD size. Another important aspect is that dispersive elements (grisms) can be inserted in the parallel beam between the collimator and the camera. Thus the instrument can be converted from a direct camera into a low dispersion spectrograph within seconds.

ALFOSC is equipped with a thinned Ford-Loral 2kx2k CCD (called W11_3) with $15\mu m$ pixels. The CCD is controlled by a Brorfelde CCD controller similar to the one used for BROCAM I direct CCD camera. A description of the performance of the CCD W11_3 and the CCD-system is given in a separate report written by A. N. Sørensen and P. Nørregaard. On the NOT the ALFOSC field is $6\farcm5$ square and one pixel corresponds to $0\farcs19$. With normal grisms spectral resolutions is from 3.0 to 40AA using a slit of $0\farcs5$. With the two echelle grisms the resolution is around 1.2AA - see the table below.

The instrument houses three wheels: an aperture wheel situated at the focal plane of the telescope and in front of the collimator, a filter wheel and a grism wheel between the collimator and the camera. All wheels have 8 positions and can be positioned to high accuracy (better than 5 μm). This ensures that multi object spectroscopy can be done - this option is however not available at the NOT.

In the aperture wheel various slit plates and aperture masks can be placed. The following slits is available at the NOT: $0\farcs4$, $0\farcs5$, $0\farcs7$, $1\farcs0$, $1\farcs2$, $2\farcs4$, $5''$, and $10''$. All slits can be used as long slits, i.e. with a length of $6\farcm5$.

The filter wheel houses filters with 60mm diameter. Here also cross dispersers (see later) can be placed. The beam between the collimator and the camera is parallel for any given point in the focal plane. However for different positions in the focal plane the corresponding parallel beams will be tilted relative to each other. This means that if narrow band filters are placed in the filter wheel, the effective wavelength of the filter will depend on the field position. It is therefore not recommended to use filters with FWHM around or less then 250AA when accurate photometry is aimed at. For broad band filters (like e.g. the Bessel system) there will be no problems. If photometry through narrow filters is wanted, the filters should be placed in front of ALFOSC, in the converging beam. It has, however, been demonstrated by Michael Andersen, that Strömgren photometry can be accurately determined if proper care is taken. For further information use the WWW; the location http://www.ls.eso/lasilla/Telescopes/2p2T/manuals/manuals.html is a good starting point.

Grisms available

The table below summarizes the properties of the grisms available for ALFOSC.

Table 1: Wavelength coverage and resolution of the grisms

Grism no	$\lambda_{central}$	λ_{blaze}	disp	RS	$\Delta\lambda$	wavelength region
3	3900	3800	180	640	5.5	3300 - 6700
4	4800	4950	220	700	8.3	3630 - 9120
5	6500	6700	220	870	7.5	3990 - 10290
6	3900	3850	110	990	3.9	3300 - 5540
7	5300	5150	110	1300	4.1	3810 - 6840
8	6500	7250	88	2200	3.0	5800 - 8350
9		5200	26	4300	1.2	3300 - 11000
10	3800	4150	460	230	17	3300 - 6400
11	5200	5100	340	390	13	4000 - 7600
12	7300	7300	910	200	37	5300 - 11000
13	5100	5450	36	4200	1.2	4780 - 5820

Wavelength and dispersion are in Å and Å/mm respectively. The resolution, $\Delta\lambda$, is in Å and for a slit of $0\farcs5$. Notes: Grism 9 and 13 are echelles. The wavelength region given for grism #13 is obtainable with a special order sorter filter.

The echelle grism #9 covers the region from 3300Å to 11000Å in the orders from 22 to 6. The echelle grism #13 covers: 3300Å - 3620Å (5. order); 3690-4440 Å (4. order); 4780 - 5820 Å (3. order); and 7000Å - 8610Å (2. order). The efficiency of this grism is slightly better than grism #9. The 3rd order from grism #13 can be isolated using an interference filter (top transmission 80%) - thus long slit spectroscopy can be made in this order. Grisms 10, 11, and 12 are recommended as cross dispersers, however, grisms 3, 4, 5, 6, and 7 can also be used.

2 FASU Basics

The FASU - Filter And Shutter Unit - houses two filter wheels called A and B (A is closest to ALFOSC), a rotational shutter and a calibration unit.

The filter wheel each each 7 positions. The 0-position is always empty. Filters of size up to 110mm can be accommodated. Special adaptors exist to accommodate 60mm (10 holders) and 90mm (6 holders) filters. If an unvignetted field in ALFOSC is wanted the filter diameter must be 90mm. Filters of size 60mm in diameter will give a circular ALFOSC field of approx 6!5 in diameter.

The calibration unit consists of an integrating sphere placed on the side of the FASU. On the integrating sphere are mounted 4 lamps: one halogen lamp, 2 Osram spectral lamps (normally Ne and He are mounted) and one hollow cathode. A glass rod from the integrating sphere, a mirror in FASU and a lens in FASU wheel A mimics the exit pupil of the telescope.

3 Installation - Introduction

ALFOSC and FASU were installed at the NOT in the period October 13-20, 1996. The basic functions of both instruments were checked and found ok. A procedure for mounting the two units was worked out, and is now documented by Jacob Clasen at the NOT. Instructions for handling of ALFOSC was given to the local staff. Local staff also used the instruments and tried to mount and align slits and grisms and to mount filters while I was there. The staff also performed regular observing.

Here I will discuss in some details the various basic tests and measurements I did. Unfortunately I was not able to do all the tests I would have liked to do. This was partly due to lack of time, but partly also due to lack of IRAF on the local computer, which made it impossible to analyze images in detail and take proper decisions on basis of this.

I have to say that the computer situation during the installation period was a mess. There was in the beginning no proper functioning computer for the control of FASU and ALFOSC. IDL were not running (as it should have done since the ALFOSC high level graphic interface is written in IDL). IRAF was not running. The printer was not functioning. The DAT tape station was not functioning. I spend hours securing my data via ftp. When I left the observatory the printer was partly functioning, but the DAT was still not working. I also have to say, that the staff was most helpful in any respect and did a very good job. However, the hardware resources were not adequate. I my opinion there should be one complete spare system (to the system that runs the instrument), there should certainly be one spare printer and one spare DAT station.

4 FASU calibration unit

The calibration unit was evaluated, and it seems that the uniformity of the illumination is not as good as we hoped. This is illustrated in Fig 1 and 2. Never the less we believe that useful spectroscopic flats can be taken with the halogen lamp. For the wavelength calibration, where the demand on uniformity is more relaxed, the unit is perfectly adequate.

The selection of lamp is the following: there are different Osram lamps: He, Ne, Zn, Cs and HgCd. The Zn and Cs lamps contain argon as filling gas, the argon lines are, however not visible in the blue region. Three different hollow cathode can be used: Th, Cu and Nb. The Th and Cu has neon as filling gas, therefore these lamps gives essentially a Ne-spectrum. Some very faint lines are visible in the UV, however, this requires exposure times of the order of 5-10min! The Nb lamp has argon as

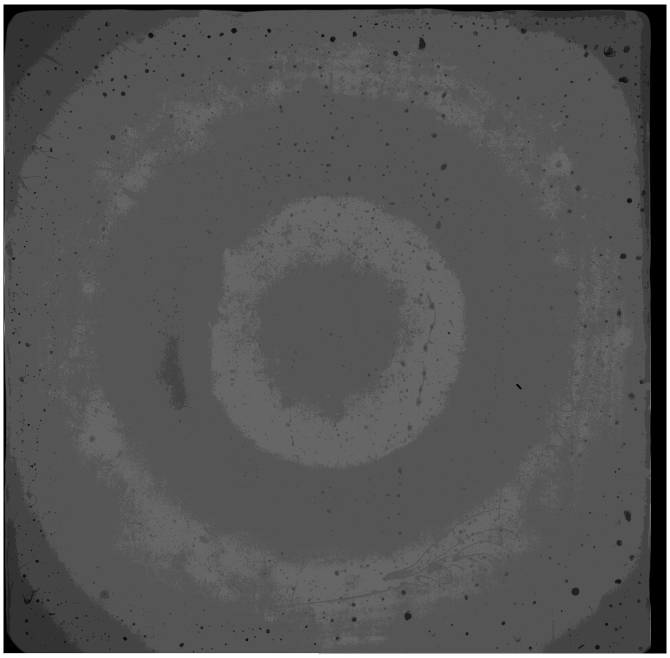

Figure 1: Uniformity of the calibration illumination

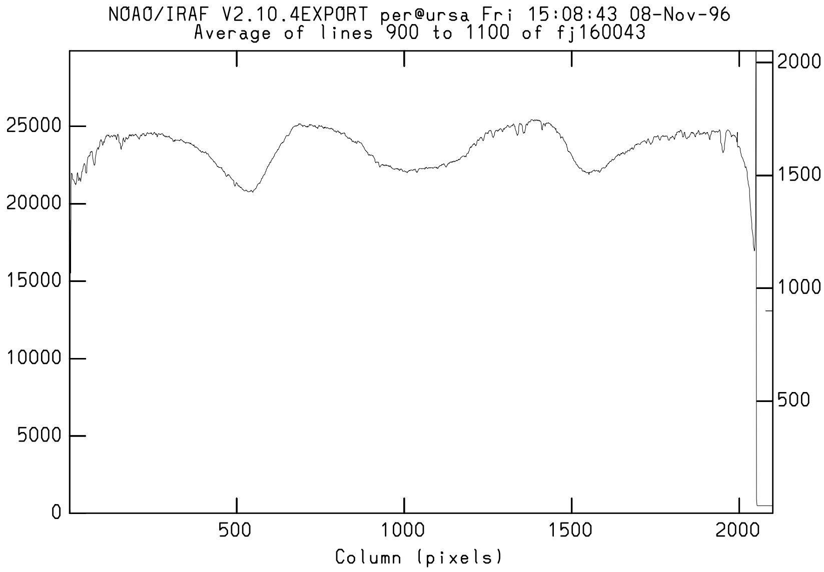

Figure 2: Uniformity of the calibration illumination; lines 900-1100 are added

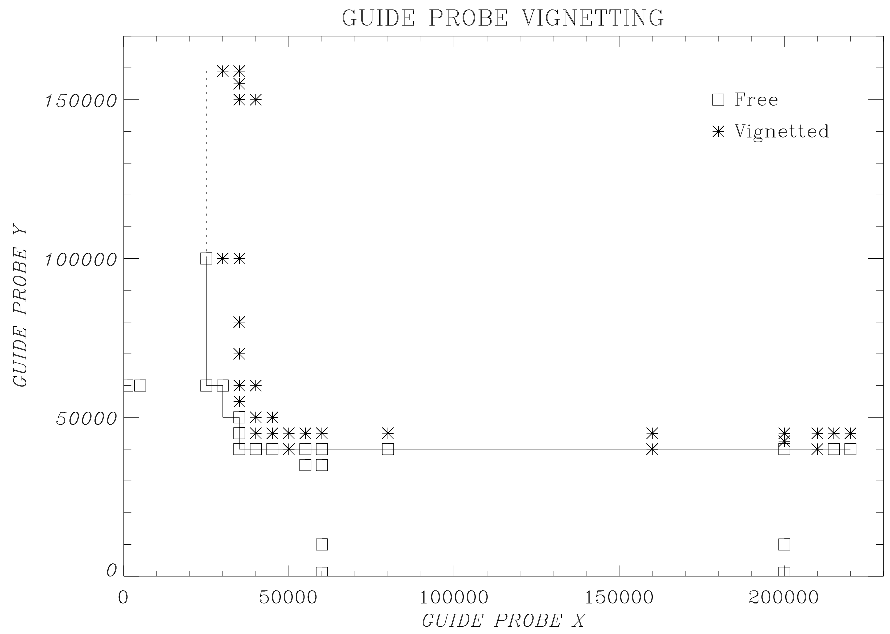

Figure 3: Guide probe vignetting

filling gas. This lamp therefore gives a nice argon spectrum, however, with weak lines in the blue.

I tested comparison spectra for grism 6, 7 and 8. My main recommendations are the following: for grism 6 nothing really good is available, however He gives a good starting point down to 3888AA, in long exposures even the line at 3187.74AA can be seen. For grism 7 Ne is ok, especially in the red. Actually, Jesper Storm has shown, in an internal report on DFOSC, that a good calibration can be obtained from Ne-lines alone using also the fainter lines in the blue part. For further information use the WWW; the location http://www.ls.eso/lasilla/Telescopes/2p2T/manuals/manuals.html is a good starting point. Nb gives a good spectrum with grism 7, which can be obtained in day time (requires exposure times of 2min). For grism 8 one get a very nice calibration with Ne.

It will be a big task to test all 8 lamps for all 11 grisms, and to work out line id lists.

5 Guide probe vignetting

Since the ALFOSC field is much larger than the fields covered be the previous CCD cameras it was essential to determine the guide probe positions which can be used without vignetting the ALFOSC field. This could be done in day time using dome illumination. Due to the lack of IRAF we had to judge vignetting or no-vignetting visually on the screen. The resulting mapping could therefore have been more precise. Never the less we obtained a quite good picture of the useful guide probe positions, which is shown in Fig 3.

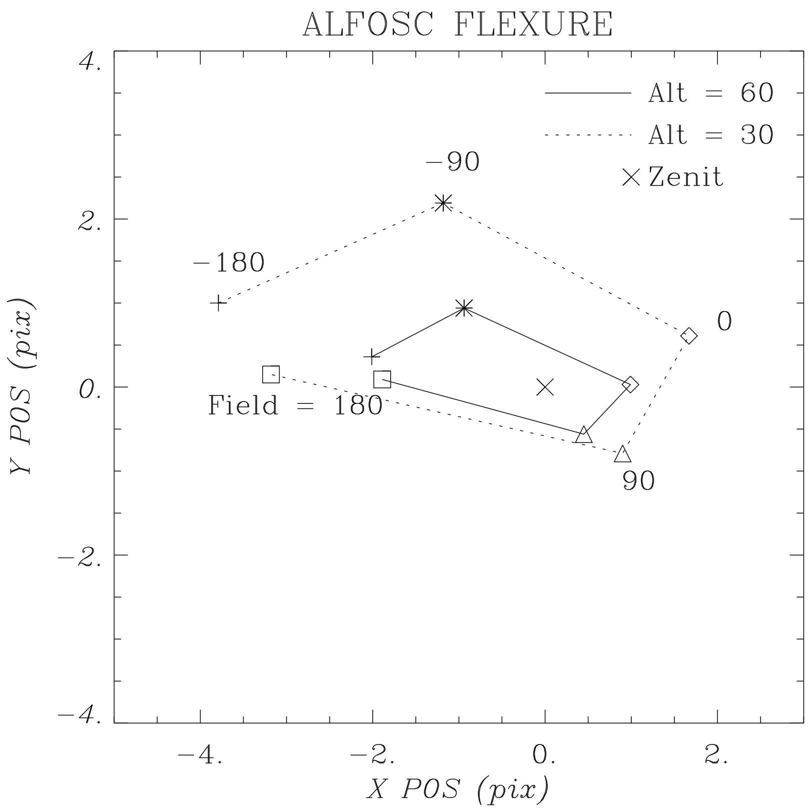

Figure 4: Flexure relative to zenith position of telescope

6 Flexure

It is essential, eg for spectroscopic work to determine the relative flexure between the aperture wheel and the CCD camera. To that end we measured the position of the central pinhole in the pinhole plate for a number of altitudes of the telescope and for a number of field positions (rotation) of the adaptor. The resulting flexure was relatively well behaved, see Fig 4. However, from the repeat measurements of some points in the diagram a hysteresis effect of up to one pixel in x and y was found. Otherwise it seems clear that the flexure can be modeled to an accuracy of at least one pixel. One should note that the flexure in the y-direction (which is the direction of the slits) is only $+2\ -1\ pixel$ from the position when the telescope is in zenith.

My recommendation would be that if a slit of 2″.5 is used one can use a fixed position of the slit. If a slit of 1″.0 is used one has to use a model for the slit position or directly to measure the slit position for the actual position of ALFOSC. If a slit of 0″.5 or 0″.4 is used, the slit position should be measured in any case.

7 Shutter correction

The ALFOSC shutter is situated between the filter wheel and the grism wheel in the parallel light beam. The shutter is a rotating plate with two open sectors. An exposure is made simply by turning the shutter form a covered position to an open position and then further on to a covered position. Therefore the usual drawback of an a shutter of the iris type - i.e. that the effective exposure time is longer in the center - is avoided.

The precise shutter time and the uniformity of the exposures has never the less to be empirically determined. The method is well known. It consists in principle of one "long" exposure where the shutter is open for a long time (relatively speaking, it could be 5 or 10 sec) and one exposure where the shutter is opened nominally the same time, but as a multiple of shorter exposures. I used 2 exposures of nominal length 5 secs and 2 exposures which were 10 times nominal 0.5 secs (here the BIAS focus sequence was used). The *shutter correction image* δ is determined using the following formulas.

$$R = \frac{10 \times (0.5 + \delta)}{5 + \delta} \quad (1)$$

and

$$\delta = \frac{5 \times (1 - R)}{R - 10} \quad (2)$$

Here R is the ratio of the 5 sec exposure and the 10 times 0.5 sec exposure. I found that $< \delta > = 0.0145$ *secs* and that the δ-image was uniform at a level of $\pm$ 0.001 *sec*. In plain words this implies that an exposure of nominal length x secs has an actual length of $x + < \delta >$ secs. This shutter offset should be monitored. It is not known to what extent it depends on eg. the temperature.

The BIAS program offers a possibility to set a correction for the shutter off-set. This should be done by the local staff.

8 Aligning Slits and Grisms

Slits and grisms were aligned in the following way.

Slits: Place the slit in question in the aperture wheel and in the light beam. Use an adequate illumination. Take an exposure. If the slit is not properly aligned (i.e. parallel to the Y-axis) the aperture wheel should be rotated. If the slit is rotated clockwise (relative to the parallel position) by an angle v *deg*, then the aperture wheel should have an off-set (for the corresponding aperture position) of $320.000 \times \frac{v}{360}$ steps. This value should be entered into the setup table containing the zero point positions for the aperture wheel. Comment: one full turn of the wheel corresponds to 320.000 steps.

Grisms: Use a pinhole in the aperture wheel. Use the halogen comparison light source. Place the grism in the light beam. Make an exposure. The spectrum should ideally run parallel to the columns of the CCD. If the spectrum is rotated clockwise by an angle v *deg* (relative to the parallel position), the grism wheel should have an off-set of $-320.000 \times \frac{v}{360}$ steps. This value should be entered into the setup table containing the zero point positions for the grisms wheel.

There is a complication here. If the correction to the zero position is too large one should rotate the grism itself in its holder. This is a one time adjustment, and should **never** be done by visiting astronomers. I did not have time to check whether this basic alignment were done for all grisms. This should evidently now be done by the staff.

How large is too large? Well the grisms have a diameter of 36mm and the diameter of the image of the main mirror on the grisms is approx 20mm. Nominally therefore one can tolerate $\pm 8mm$ from a position of the wheel where the grisms is truly centered. However, taking the various tolerances into account and playing safe one should use a tolerance of $\pm 4mm$. This corresponds to ± 1.860 *steps*. But since the true zero point of the grism wheel is not known better than approx. 500 steps, one ends up with the following: **the final position of the grism wheel for any given aligned grism should never deviate more than 1.500 steps from the nominal zero position** (i.e. the values 40.000, 80.000 etc steps).

It is recommended that the staff establish a software tool for aligning slits and grism as soon as possible. Ie. that an IDL program is written which as input takes the image of the slit or the grism spectrum, and which calculates the necessary positions and angles. Although the basic operations are simple, it can be quite time consuming to do alignment of several slits and grisms.

9 Image quality

A key figure for ALFOSCs performance is the quality of the direct exposures. The best way to assess this is of course to obtain stellar exposures in good seeing conditions. Unfortunately the seeing was not very good under the installation period. The best images registered were around $0\rlap{.}''8$. This investigation therefore has to await good seeing conditions.

Focus for different filters

What we did was to investigate the focus and the quality of the focal plane using filters in ALFOSC and two Hartmann masks, Hartmann1 and Hartmann2 in the grism wheel.

If the instrument is not in focus this will cause images of pinholes taken through the two masks to shift in position. When the hartmann-shift is zero, the instrument is in focus. Based on practical measurements the following formula for the focus was found, here X_{h1} and X_{h2} are the x positions of the pinhole in respectively the Hartmann1 and the Hartmann2 exposures.

$$Focus \quad = \quad Old\ Focus - (X_{h2} - X_{h1}) \times 1500 \tag{3}$$

Using this formula it is quite fast to determine the best focus for a given filter. We did that for the following 4 filters: Gunn r, Bessel B, Bessel V and Bessel I. We found the following best focus (in the center of the field): Gunn r: 4820; Bessel B: 4850; Bessel V: 4490 and Bessel I: 4990. In order to evaluate these figures one has to know the scale of the focus movement - and what change one can accept of the focus from studying the spot diagrams of the optical design.

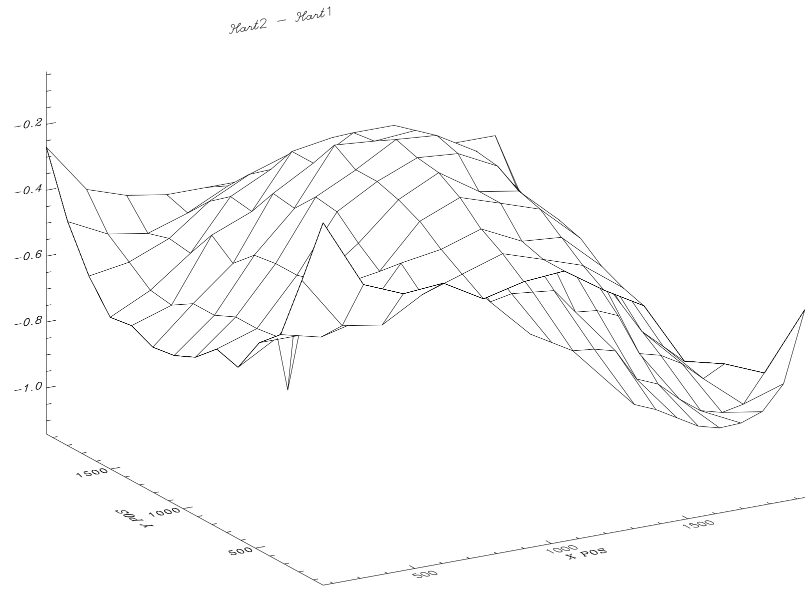

Figure 5: Surface plot of the focal plane in Bessel V

The scale is such that 6.580 focus units (in the graphic user interface) corresponds to a linear shift of the camera of 1mm. From the spot diagrams of the optical design one find that a focus variation of $\pm 0.040\mu$ can be tolerated. Actually this tolerance applies strictly to the F/8.6 1.5m meter telescope for which ALFOSC was designed. The tolerance for the NOT F/11 is probably around $\pm 0.050\mu$. This then translates to tolerance of ± 330 focus units. It is therefore seen that the filters Gunn r, Bessel B and Bessel I have the same focus. However, it is clear that the Bessel V filter we used must have some optical power, and that the focus for this filter should be changed relative to the other 3 filters.

The morale is therefore that the focus of a given filters to be used in ALFOSC should be checked.

The focal plane in Bessel V

The focal plane in Bessel V was investigated using the pinhole plate in the aperture wheel, the Bessel V filter in the filter wheel, and the two Hartmann masks in the grism wheel. From the shift in the Hartmann images of the pinholes, the form of the focal plane can be determined over the whole field. The resulting diagrams is shown in Fig 5 and Fig 6.

The quantity plotted is the shift in pixels: $x_{h2} - x_{h1}$. It is seen that this shift goes from ca. -0.2 to -1.0. This then corresponds to a peak-to-peak change in the focal surface of $(1.0 - 0.2) * 1500/6580$ or 180μ. It could be argued that since the Bessel V filter have some optical power, it would probably have been better to make the above investigation with another filter. Also it is seen the measurements were done a bit out of focus. So the true figure is probably rather 150μ peak to peak. Never the less the figure compare well with a value of 110μ found for DFOSC *using the smaller field covered by a 1k $\times$ 1k Thompson CCD*. Thus a figure of 150μ peak to peak is probably realistic for ALFOSC. This figure is also about the same order as twice the tolerance of the focus mentioned above.

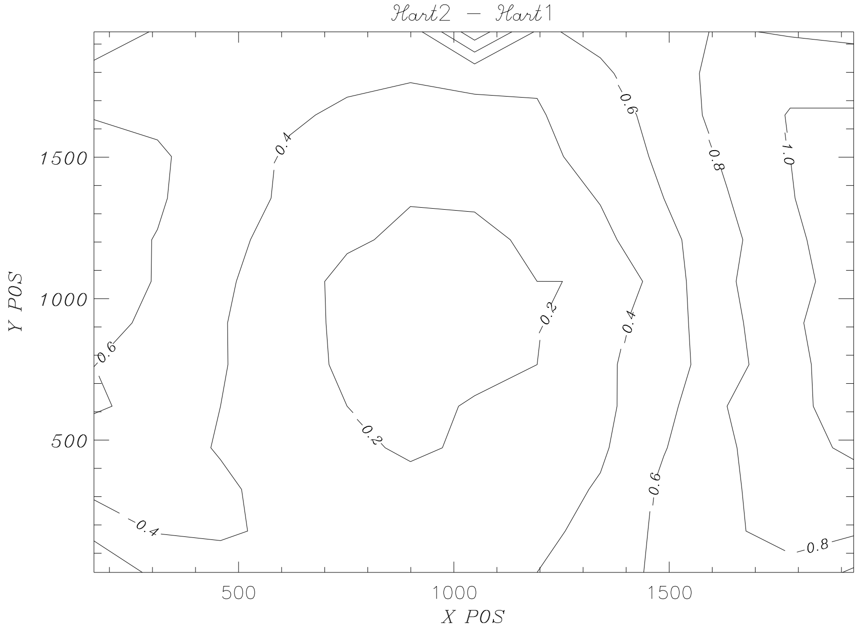

Figure 6: Contour plot of the focal plane in Bessel V

Finally it should be noted, that as seen from Fig 5 and Fig 6, the best focus obtained for the center field position is not the best over-all focus. The best over-all focus is in this case at a value of -0.40 in the shift of the two Hartmann exposures. Since the central value is -0.17 this means, that the best over-all focus is +350 step above the value found for the center.

The whole procedure relies on the assumption that the plastic pinhole plate actually is optical flat. This is probably not the case. Actually once I noticed a change of focus of around 100 focus step (for a certain filter) after having taking some black tape off the pinhole plate.

10 Optical quality - spectroscopy

In principle this can be investigated using a proper light source (spectral lamp), a grism and two Hartmann masks which should be situated in the filter wheel and covering the two halfs of the beam which is in the direction of the dispersion. Unfortunately due to the lack of IRAF we were not able to do this investigation. What we could do, however, was to measure the FWHM of unblended and well distributed lines. Here the combination of the Ne Osram lamp and grism 8 was well suited. We also used the combination of the He Osram lamp and grism 7. In both cases we used a slit of width $0\farcs5$ The result of the measurements are given in Fig 7 and Fig 8. The FWHM of the slit was measured without filter to 3.2 pixels.

Several effect is at play here. The direct measurement of the slit is done in white light and can therefore not be compared with the FWHM of the spectral lines directly. Two other effects are important. The first is the anamorphic magnification which for grism 8 changes from 0.90 in the red part to 1.15

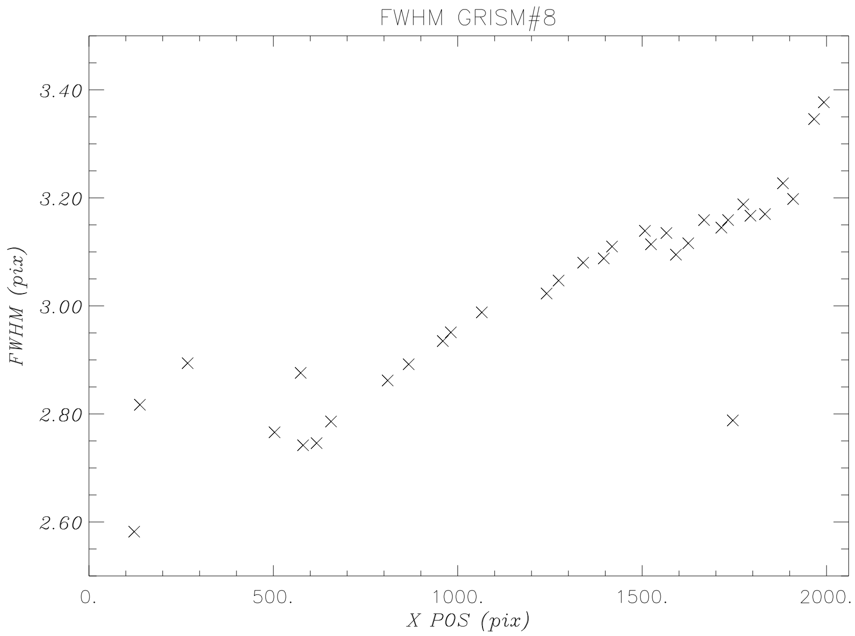

Figure 7: FWHM of Ne lines as function of spectral position for Grism 8. Red is to the left

in the blue part of the spectrum. For grism 7 the anamorphic magnification changes from 0.94 in the red part to 1.08 in the blue part of the spectrum. It is seen that the change in FWHM for grism 8 and 7 can be explained completely by the anamorphic magnification. However, there is also an unknown effect due to the fact the penetration of the photons into the chip depends on wavelength (the redder photons penetrate deeper).

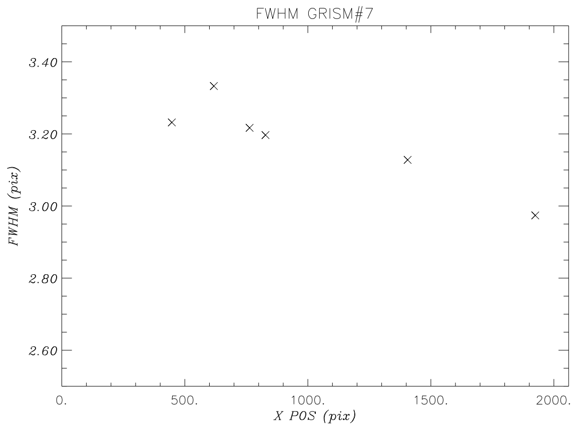

Figure 8: FWHM of He lines as function of spectral position for Grims 7. Red is to the right

Table 2: Measured count rates in ke^{-}/min for a magnitude of 15 in the actual filter

	Filter			
	Bessel B	Bessel V	Bessel R	Bessel I
count rate	540.0	640.0	540.0	560.0

Note: the count rate in Bessel R was determined from measurements in Gunn r

11 Putting an object on the slit

Since the instrument has no slit viewing - which in any case would be of limited value, it is essential that a fast an accurate procedure is worked out for putting an object in the middle of a slit.

Suppose the center of the slit is at X_s, Y_s and that the object position is X_c, Y_c while autoguiding. Then do the following: convert the difference in X and Y to arcseconds in α and δ. Stop autoguiding and move the telescope West (or East) and North (or South) so that the object will be in center of the slit. Then move the autoguider opposite the same distance and start autoguiding again. This procedure means that positioning is done with an accuracy set by the positioning of the autoguider and not with the precision of setting the telescope.

For the slit E-W (field -90) the signs and numerical constants are the following: If the telescope is moved West autoguider Y should be increased, if the telescope is moved North autoguider X should be increased. One pixel correspond to $0\farcs1893$ and $1''$ corresponds to 139.80 autoguider steps. If the slit is North-South (field 0) the signs are: if the telescope is moved West autoguider X should be decreased, and if the telescope is moved North autoguider Y should be increased.

It is recommended that the staff as soon as possible implement a procedure for doing this on an automatic or semi-automatic basis. As a first step a batch could be written (probably most easily in IDL) which as input takes the slit position and the image of the object. After pointing on the object the program calculates the position of the object and the necessary telescope and autoguider off-sets. Next step would be that this information automatically is send to the telescope control system. If done by hand the "putting an object on the slit" can be quite time consuming.

12 Count rates - Photometry and Spectroscopy

The count rates in the standard filters were determined on the photometric night October 17-18, 1996. The two Landoldt std. fields Mark A and SA113 (centered on L1) were observed at an airmass of 1.15. The following filters were used: Bessel B, Bessel V, Gunn r and Bessel I. The derived count rates are given in the table below.

The spectroscopic measurements were done on the Oke std. star BD +28 4211 using grisms 6, 7 and 8. A slit of 10" and an exposure time of 120 sec was used.

The count rates in both direct imaging and in spectroscopic mode compare well with count rates obtained with DFOSC on the Danish 1.54 meter provided that account is taken of a) the different mirror sizes and b) that the CCD W11_3 had a lower sensitivity at the ALFOSC.

Table 3: Measured count rates in $e^{-}/sec/AA$ for a monochromatic magnitude m_{ν}= 12.0

	Wavelength (nm)								
Grism	350	400	450	500	550	600	650	700	750
#6	75	146	148	128					
#7			146	150	148	137	150		
#8						145	130	113	93

Note: Grism 6, 7 and 8 have respectively 1.5, 1.4 and 1.3 AA per pixel

13 Extras: Lyot stop, Focus pyramid and Coronographic mask

We also brought a lyot stop, a focus pyramid (both of which can be mounted in the grism wheel) and a coronographic mask. None of these were tested.

The Lyot stop is a stop which is placed where the pupil is imaged (approx at the position of the grism wheel) and which then blocks out the stray light. Before using it, it is, however, necessary to ensure that no light is lost. Measurements through the Lyot stop should therefore be done by at slightly different positions of the grism wheel, and compared with measurement using a completely open position in the grism wheel. These measurements were not done.

The focus pyramid splits the light beam from a star in 4 parts, resulting in 4 images of the star. The relative position of these images will depend of the focus of the telescope and should be empirically calibrated. The method is potentially fast and robust.

The coronographic mask is a glass plate with 4 opaque spots of diameter 0.2, 0.4, 0.8 and 1.2mm, corresponding to $1''\!.5$, $2''\!.9$, $5''\!.9$ and $8''\!.8$. This glass plate can be mounted in the aperture wheel using a special aperture plate holder.

14 CCD - Bias

It was beyond the scope of my investigation to also cover the CCD system. However, during the reduction of the various exposures done in connection with the installation it became clear that the bias level is very badly determined.

As an example the exposures taken for the shutter correction (where the CCD was binned 8 in both x and y) had a value of 506 ADU in the overscan region. However, 5 bias exposures taken just after the 4 shutter correction exposures had a level which varied from 515 ADU to 565 ADU in the y-direction.

When the CCD is window'ed there is no overscan, and the bias level is therefore unknown at a level up to probably 100ADU. This is not acceptable.

15 Conclusions

- **ALFOSC can be offered to visiting astronomers now**

  ALFOSC is well tested and its performance is as expected. Thus the instrument can without any doubt be offered on a regular basis to visiting astronomers.

- **Main parameters are determined**

  Main parameters such as count rates, image quality, guide probe vignetting, flexure, shutter correction and alignment procedures are documented in this report.

- **Remaining hardware work**

  Some hardware work remains to be done by the staff: checking the one time gross alignment of all grisms, measuring the full set of slits, documenting suitable spectral light sources for the various grisms and to control the focus of standard broad band filters in ALFOSC. However, none of this prevents offering ALFOSC to visiting astronomers on a regular basis.

- **Recommended software tools to be established**

  It is strongly recommended that the local staff establish software tools for aligning slits and grisms and - most important - to put an object on the slit.

Acknowledgments

Thanks to the local staff, the Danish team which participated in the installation and to Josefa Masegosa and Justo Sanchez from Granada who participated in the testing of ALFOSC.