Wide field optical and IR spectroscopy at the ING: present and future prospects.

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Abstract

The present status and performance of the fibre positioner AUTOFIB2 and spectrograph WYFFOS are reviewed. After extensive re-engineering of the AUTOFIB2 robot and fibre module, the system is now *reliable*, setting up a science field in under 30 minutes with better than 10 μm internal accuracy (the original specifications). Since the rebuild AUTOFIB2 has been scheduled on some 50 nights and undergone more than 50000 fibre movements with only one failure (and a number of back illumination failures of a minor nature). WYFFOS is now fully commissioned in both reflection and 'echelle' mode.

By summer 2000 both the small fibre module (1.6 arcsec diameter) and the WYFFOS long camera will be commissioned. These upgrades will make this system amongst the most sensitive on any 4 m telescope. A series of relatively minor software and fibre module upgrades are also proposed (some of which will be implemented soon) which will allow 150 fibre movements in 10-15 minutes and crossing fibres.

Further in the future we propose the development of a fibre module and WYFFOS optics optimized for the near IR and also a small fibre module containing 600 fibres (2 fibres per button) that at the very least will be useful for sky subtraction and beam-switching (depending on technological developments).

Key words: fibre spectroscopy: wide-field spectroscopy : IR-fibre spectroscopy

1 Introduction

The WYFFOS spectrograph is installed on a dedicated optical table in the GHRIL cabin at nasmyth on the WHT. Its design is similar to the white-pupil

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design of Baranne, in which a dioptric collimator is used in double pass (near-Littrow) mode with a reflection grating to form an intermediate spectrum close to a concave spherical relay mirror. the current system uses a Schmidt-type camera to re-image the intermediate spectrum onto the detector. The function of the relay mirror is to image the collimator pupil onto the camera pupil. During commissioning of the spectrograph a problem was discovered with the camera which resulted in a large scattering background. RGO staff traced this problem to vacuum grease not performing to its specification.

AUTOFIB2 is the WHT prime focus pick and place robotic positioner. In its original form it was a development of the original AAT AUTOFIB but with the ability to 'see' fibres via back-illumination and a camera mounted in the gripper, greatly aiding the fibre placement accuracy. Commissioning of AUTOFIB2 started in 1994 and was characterised by unreliability in positioning and field setup completion. In August 1995 a seizure in the gripper's 'z' axis mechanism led to the ING starting an on-island re-engineering programme for the instrument. After an extensive testing program, problem areas in the original design were identified. Modifications were made with the primary goal of realising the original specifications for the instrument and making the longterm performance of the instrument more reliable.

2 Current Performance

Since delivery AUTOFIB2 has been equiped with a module containing some 126 science fibres each with a diameter subtending 2.7 arcsec on the sky. To aid installation, the 26 m runs of fibres are split on the telescope top ring using optical couplers. The current WYFFOS camera was designed with a 1024 pixel^2 Tek chip held on a cold finger. This design did not allow imaging of the entire WYFFOS slit length, but was the only design that fitted on the optical table (an original design specification). Hence, one bundle (15 science fibres) has remained unimaged since delivery. Of the remainder, 12 fibres are damaged in some way rendering them unusable (50% of these are disabled because of poor transmission). Recent measurements of sensitivities indicated that a $M_{AB} = 16.8^m$ gave 1 detected photon sec^{-1} Å^{-1} with the spectrograph in reflection mode. Echelle mode (really a 632 lines mm^{-1} grating used in high orders) was recently commissioned (August 1998) and in orders 4 and 5 the sensitivity was about 0.5 magnitudes worse while in the bluer orders the situation was worse still (probably caused by a combination of fibre and filter transmissions).

Figure 1 shows the variation of fibre transmissions from run to run which demonstrates the unreliability of the fibre couplers. The variation shows that despite much care taken in joining the fibres using refractive index matching

Table 1
Main parameters for the current AUTOFIB2 plus WYFFOS system

Prime Focus	
Field diameter	1 degree
Unvignetted field	40 arcmin
Plate scale	17.6 arcsec mm^{-1} (57.0 μm $arcsec^{-1}$)
Focal ratio	f/2.81
AUTOFIB*2*	
Fiducial fibres	10x7–fibre guide bundles, res. 1 arcsec
Autoguider imageguides	1 fixed, 1 movable
Science fibres (Large)	126x153 μm (2.7 arcsec)
Cycle Time	~15 sec per fibre
Positioning accuracy	better than 10 μm (absolute)
Science fibres length	26 m
Slit optics (Large)	Sapphire microlenses
WYFFOS	
Design	Baranne white pupil type
Collimator	f/8.2; $f = 820$ mm
Short Camera	f/1.2; $f = 132$ mm
Dispersion: Reflection	11.5–0.8Å $pixel^{-1}$
Resolving Power: Echelle	~8000
Detector	Thinned Tektronix TK1024
Pixel size	24 μm

fluid transmission, repeatability was not obtainable. Furthermore, the fact that some improve while others do not, is indicative of an unreliable connection within the coupler. We suspect that this is one of the main reasons for the relatively poor overall performance of the current system, and would hope to be measuring in excess of $M_{AB} > 17^m$ with continuous fibres and possibly as high as 17.5^m.

3 Funded Enhancements

A number of enhancements have been under development for several years but their manufacture has been badly effected by the closure of the RGO.

- AUTOFIB*2 Small fibre module:* These fibres have 90 micron diameter which subtends 1.6 arcsec on sky. This is the best compromise diameter allowing much lower sky contamination for unresolved sources (by a factor of 2.8), while still accommodating astrometric and positioning limitations. Fibres in this module will be continuous from the field plate to the WYFFOS slit

Table 2
Physical characteristics for the WYFFOS reflection gratings with the Large and Small Fibre modules. The H1800V grating is actually from the INT's intermediate dispersion spectrograph and is used via a special adaptor.

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

Table 3
Physical characteristics for the WYFFOS Echelle Mode with the Large Fibre module. The filter throughput curves for each wavelength region are shown in Fig. 2.

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

unit which we expect will improve the efficiency of the system. Furthermore, fiducial coherent bundles will be used for alignment (rather than the semi-coherent bundles of the large fibre module). The fibre module is under construction by ING staff and is due for completion in 2000/2001.

- *Fibre placement speed:* Current setup of all fibres takes about 30 minutes, but we believe modifications to the current (x, y, z, θ) motor sub-systems would allow this to be dramatically reduced to less than 15 minutes. Investigation of commercially available parts is being made a high priority with the overall aim of getting the setup time per fibre to $< 5\,\mathrm{sec}$ (preferably $< 3\,\mathrm{sec}$).
- *The* WYFFOS *Calibration box:* Due to the closure of RGO this was delivered to La Palma in a non-operational state. The system has been re-engineered and is awaiting mounting at the broken cassegrain focus. Installation of the

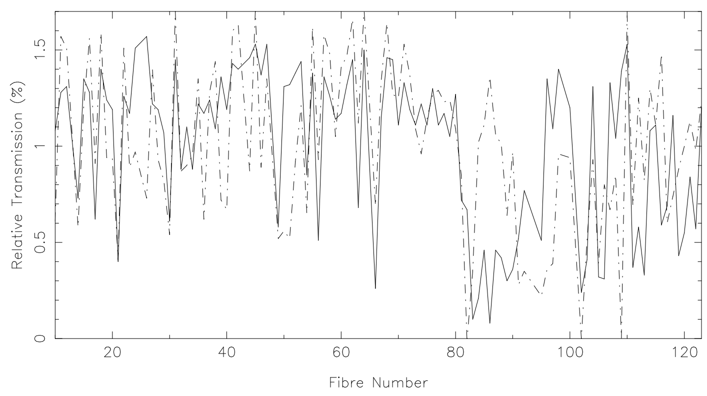

Fig. 1. The variation in relative fibre transmissions between two runs in 1997 (dotted and solid lines). In each case the fibres were setup in a ring hence all are equally affected by vignetting and a well exposed twilight flat taken.

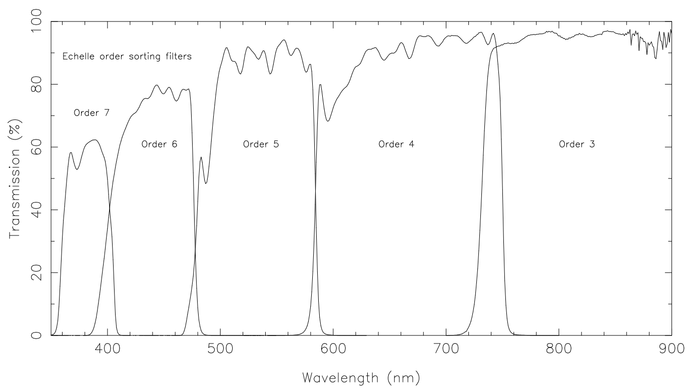

Fig. 2. The Echelle mode interference filter transmission curves.

calibration box will be before the first run in semester 2000A.

- *The* WYFFOS *long camera:* The current spectrograph camera has a dedicated and integrated 1024 pixel^2 Tek chip as detector and is unable to image the full length of the spectrograph slit (hence, one fibre bundle is never imaged). The long camera design will overhang the current WYFFOS enclosure by some 30 cm. It has an external focus and will deliver a flatter focal plane. The current Sue Worswick design for the long camera produces a $\sim$55 mm field with about 10% vignetting at the edges. A mosaic of 2 4k$\times$2k EEV42-80 type devices (13.5 μ pixels) provides the silicon detection area to cover this field of view. In the future it is likely that a similar 2 CCD mosaic of red-optimised MIT/LL chips will also be provided. The EEV42-80s and the MIT/LL (CCID-20 types) have excellent QE's ($\sim$80% peak at 4000Å and 7000Å respectively, providing very sensitive near-UV – Optical – near-IR coverage). The smaller pixel size will allow significantly better modelling of the spectrograph scattered light and spatial sampling of the fibre flux profiles. This project is expected to start in the next few months and be completed before summer 2001.

Several of the above items deal with observational efficiency gains in the current system (i.e. placement speed and calibration box), while the others are genuine enhancements to the system. In terms of efficiency gains, the fibre placement speed will clearly have on-sky time saving implications as soon as it is implemented, although, any upgrade should not jeopardize the current reliability of the instrument.

The major gains from smaller fibres and the long camera are for objects with brightnesses close to that of the sky itself. As a rough indication the current system produces S/N$\sim$6 per pixel on a $B \sim 21.0$ object in about 3600 sec of integration (with a R1200 grating). Assuming an improvement of 50% arrising from the continuous fibres, gains of 20% to >100% from the QE of the Long-camera CCDs and considering the $\sim$2.8 decrease in sky background from the smaller aperture fibers, then we expect to be able to reach a S/N$\sim$8 for $B \sim 23$ in approximately 2 hrs of exposure (with the R300B; giving 6Å pix^{-1}). Further gians due to better reduction techniques (spatial sampling and scattered light modelling) with the small pixels in new CCDs will also contribute.

4 Possible Major Upgrades

None of these projects are currently funded but are under discussion and feasibility studies are underway by ING staff. The community are encouraged to comment on them and other aspects they feel would enhance the AF2/WYFFOS system.

- *Fibre crossing.* The current AUTOFIB2 system does not allow fibres to be crossed, but crossing could allow up to 50% more targets to be selected (depending on target density). The technology to achieve this lies in the fibre tensioners and retractors and is already in existence (eg 2dF at the AAT), but substantial effort would be required to implement this within AUTOFIB2 essentially requiring the construction of a further fibre module.
- *Integral fields at the Prime Focus.* The greater imaging capability of the long camera plus modern detector combination offers the capability of offering multiple integral field units at prime. Limitations on fibre core diameter mean that the fibre 'pixels' would probably have to be > 1 arcsec and possibly 10 arrays of about 10x10 fibres could be imaged on the detector. For added versatility the IFU's could be incorporated into an ordinary fibre module with a few hundred single fibres.
- *A 300/600 fibre module.* We are optimistic that in the near future a fibre module containing 300 fibre buttons could be setup in 30 minutes. In the

original specifications for AUTOFIB2 this was considered an acceptable on sky 'dead time' for setting up 150 fibres. The instrument efficiency could be further improved if it is arranged that each button contains *two* fibres: one per target and local sky. In principle one of these fibres could have some latitute for movement relative to the other in effect creating a *beam-switching module* for 300 objects.

This kind of system would certainly be superior for spectroscopy of faint objects (>21 mag), to any other system available. In terms of large scale structure the 2df, Chinese LAMOST or the SLOAN project will be superior as these facilities have systems with wide fields of view (>1 degree), large fibres, and are dedicating large amounts of telescope time to this project. However, for all kinds of clustering experiments the AUTOFIB2 system would be superior – especially for extremely faint objects where the relative amount of time spent on fibre rearrangements compared to that collecting photons is minimized.

- *A near-IR spectroscopic facility.* We are currently in the early stages of feasibility study aimed at determining the usefulness of WYFFOS in the H and J wavebands. The long camera is being designed so as to give a useful IR performance and will be able to mount the INGRID detector. The IR performance of the other elements in WYFFOS is presently being determined. At least at this stage this seems like a cheap, quick, and relatively easy upgrade although a full feasibility study would be needed.
- *Remake the large fibre module with continuous fibres.* The diameter of these fibres was supposedly selected to match the angular size of a $z=1$ galaxy. In winter months and with extended objects the large fibre module may well remain more suited to the observational conditions. However, the current module has a number of dead fibres and within a few years will need significant maintenance (remember a dead fibre means a loss of a radial sight-line). Just remaking the large fibre module using continuous fibres from the focal plane to the spectrograph slit would make a significant improvement in the performance and reliability of the fibre transmission. Some of the other developments and enhancements outlined here could also be included (not least having 300 crossable fibres).