6DF SEES THE LIGHT!

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6dF (Six Degree Field) is the new robotic multifibre spectroscopy system for the UKST. It allows 150 targets to be simultaneously observed over a field 5.7 deg diameter at resolutions of R = 600 - 5000. It offers a unique facility for spectroscopic follow-up of bright (V<17) targets with source densities in the range 1 – 50 deg^{-2} – i.e. almost anything too sparse for effective use with 2dF but with too many objects for efficient single-slit spectroscopy. In particular, the first large surveys in new wavebands (IRAS, ROSAT, 2MASS, HIPASS) are almost invariably wide-angle but shallow, ideally matched to 6dF follow-up. Many other projects demand all-sky coverage, and for these a Schmidt is the only realistic wide-field multiplexing option.

The Road to 6dF

The amount of information received by a telescope, or the number of galaxies observable in a given integration time, depends on the product of aperture and field of view. In this respect, the UK Schmidt is almost identical to the AAT+2dF or Sloan, and easily beats all other telescopes. It was the imposing $A\Omega$ (Aperture x field of view) product of the UKST that led Dawe and Watson to suggest in 1984 that multi-fibre spectroscopy could be carried out with the telescope. The original proposal included the idea of an automated fibre positioner. However, when multi-fibre spectrography was offered at the UKST using the FLAIR prototype (1985), the PANACHE upgrade (1988) and the FLAIR II system (1992), only manual positioning of the fibres was possible due to budgetary constraints. Despite this, useful science was obtained from all versions of the system, particularly FLAIR II during its heyday in the 1990s.

Upgrades to the FLAIR II spectrograph during that period resulted in improved sensitivity, which highlighted the principal deficiency of the system. This was that the manual fibre-reconfiguration time could easily exceed the necessary exposure time on a given field by a factor of more than four. Even with new magnetic buttons introduced in 1998 (partly to test the feasibility of 6dF), no more than two fields per night could be observed. This severely limited the usefulness of the system for the large-scale spectroscopic surveys to which the telescope is intrinsically well-suited.

A proposal by MMC, QAP, WS, Gary Mamon (Paris) and others to carry out an all-southern-sky galaxy redshift survey — with the unique additional component of a subset peculiar-velocity survey — was a key element of an options paper for the UKST, presented to the AATB in August 1997. As a result of this, a Phase-A study for an automated fibre positioner was carried out, and construction was approved by the Board in March 1998. Its preliminary anticipated cost was ~\$A0.6M and the survey was expected to start in April 2001. The scope of the project was then increased in September 1999 after a submission to ATAC by QAP and FGW to include the implementation of a new CCD detector system for the original FLAIR II spectrograph. This was approved at an extra cost of \$A150k.

6dF shares many features with OzPoz (the fibre positioner being built by the AAO for the VLT): e.g. an R-theta robot allowing a curved focal surface to be configured (even if it is in the opposite sense) and a zero-friction pneumatically-controlled fibre-button gripper. These features alone reduce the number of motor-driven degrees of freedom from the 5 of 2dF to just 2 for 6dF. The robotic software is based on the 2dF software, modified for an R-theta robot and the 6dF computer interfaces, and has provided valuable feedback for the OzPoz software development. Detailed technical descriptions of 6dF may be found in Parker, Watson, & Miziarski (1998 ASP 152) and Watson et al. (2000 SPIE 4008). A broad outline of the instrument follows.

Figure 1. Kristin Fiegert and the 6dF positioner

Description

The main components are:

1) two interchangeable 6 deg diameter field-plate units (each with a permanently attached fibre feed and slit output block). These can be loaded either into the robot for reconfiguration or into the telescope for observing. The only time-on-target lost with this “double-buffered” arrangement is in the exchange between one field-plate and the other in the telescope, and the associated calibration exposures which together add overheads of around 30 minutes;

2) optical cables containing 150 x 6.7" science fibres and four field acquisition and guide-star bundles for each field-plate;

3) a robotic pick-place fibre positioner housed in an enclosure within the dome. It incorporates a back-illumination facility for the fibres to enable accurate positioning/location of fibre buttons. Hence when a field-plate unit is unloaded from the telescope, the attached slit-unit must also be unloaded from the spectrograph and transferred to the positioner;

4) the refurbished FLAIR II spectrograph, which is also mounted on a rigid optical bench on the dome floor. This has been shown to result in extremely high spatial and wavelength stability;

5) the upgraded CCD system, incorporating a 1k x 1k 13μ pixel Marconi CCD47-10 device and SDSU-2 detector controller. The new detector system, together with the *CICADA* operating system and operational interface, have been supplied under contract by the RSAA at ANU;

6) new robotic control software, and a new version of CONFIGURE allowing efficient allocation of fibres to targets;

7) new 6dF specific data reduction software called 6dFDR based on the equivalent 2dFDR package allowing rapid spectral reduction.

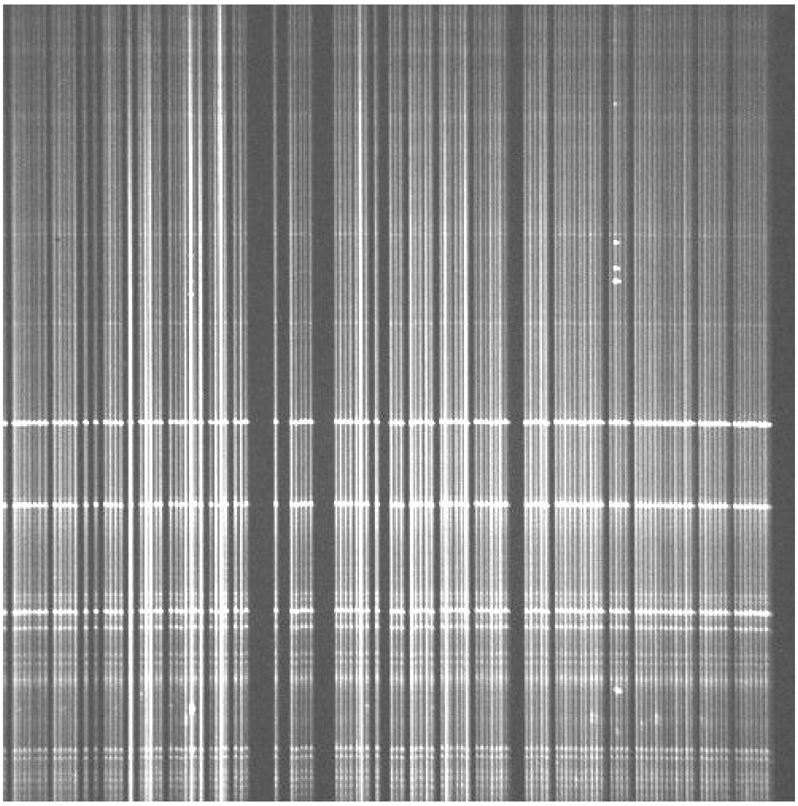

Figure 2. A raw data frame taken with 6dF of obscured galaxies in Vela with ~2 mag. blue extinction. The spectra from each fibre run vertically, with blue at the top and red at the bottom. The aligned bright spots are night sky lines, and other bright spots are emission lines from the target galaxies.

Commissioning and current status

The camera with new chip and controller was delivered in November 2000. Camera commissioning was completed by Christmas, except for quite bad comatic aberrations evident at the edges of the imaged area. Such aberrations were always present in the camera at some level but are now more obvious and severe. This is due partly to the bigger physical imaged area and larger slit length/fibre numbers, but also to the difficulty of re-aligning all the optical components in such a fast camera, including the new CCD and field-flattening lens. Preliminary adjustment and corrections have already significantly improved the imaging.

The robot was delivered to Siding Spring in late February. There then ensued a significant ‘shake-down’ period. There were many problems with getting the astrometry right, the inherent R-theta coordinate system turned out to be a real minefield; also the absolute calibration of the plate scale proved to be quite tricky given button virtual focus offsets and the like. Other problems were the reliability of the retractors (now greatly improved by the retrofitting of internal teflon glide sheets in each retractor by Kristin Fiegert), and the fragility of the guide bundles which may necessitate a re-design down the track. The throughput is somewhat down on original expectations due to the unforeseen introduction of excessive Focal Ratio Degradation (FRD) in the fibres, mostly caused by the spare fibre loops in the retractors. In general, most of these problems are related to the difficulty of shoehorning the fibre retractors into the existing physical envelope of the Schmidt photographic plateholders.

The robot itself has worked very well, with only a handful of hardware errors. Configuring speed is still a little slow, currently at about 30 seconds per fibre for a combined park and placement operation with an 18 sec / 12 sec split). However this is adequate for most programs and there is plenty of scope in the robot operation for significant improvement.

Basic commissioning is now complete — fields can be accurately and rapidly acquired with the light going down the fibres. Science-grade observations have already commenced. Figure 2 shows 1 hour combined data for a field of galaxies (optically and 2MASS selected) behind the Milky Way in Vela at latitude b=7.5°, and Figure 3 shows the reduced spectra from a series of 12 target fibres. Currently, the efficiency is around 10% (top of atmosphere to detected photons) at 5500Å.

Various improvements are still underway: a new ring of calibration lamps is being fitted to the telescope top end with full remote operation; the camera misalignment responsible for the coma in the corners of the CCD images is still under investigation but improvements have already been obtained; some of the guide fibres are set to be replaced with a new design to tighten up the acquisition and reduce the effect of field rotation errors; both field plates have now been retrofitted with a 3-faceted slit unit to more adequately match the curved ideal slit shape required by Schmidt optics; the collimator mirror is to be rotated to reduce light losses in the spectrograph by accepting the full beam emitted by the fibres. Furthermore, we have ordered new ultra-efficient VPH gratings from Ralcon which can replace the current reflection gratings for many projects. These and other smaller modifications should lead to an estimated 30-50% efficiency gain! We are basically set to start the main 6dF Galaxy Redshift Survey (6dFGRS) in June, a mere two months later than originally proposed more than two years ago.

The 6 Degree Field Galaxy Redshift Survey

The primary motivation for 6dF is the all southern-sky spectroscopic galaxy redshift survey. The principal data source for this will be the wonderful 2MASS data, the first all-sky digital imaging survey (http://www.ipac.caltech.edu/2mass). This gives the first clean picture of the Local Universe, unaffected by current star formation or dust in our own or external galaxies – it is the natural place to study Large-Scale Structure, but this has not been possible until now because of the lack of source material.

The primary 6dFGRS sample will be 120,000 galaxies brighter than K_s=13. The median redshift depth is 0.05 and the sky coverage will be δ<0, |b|>10, outside the

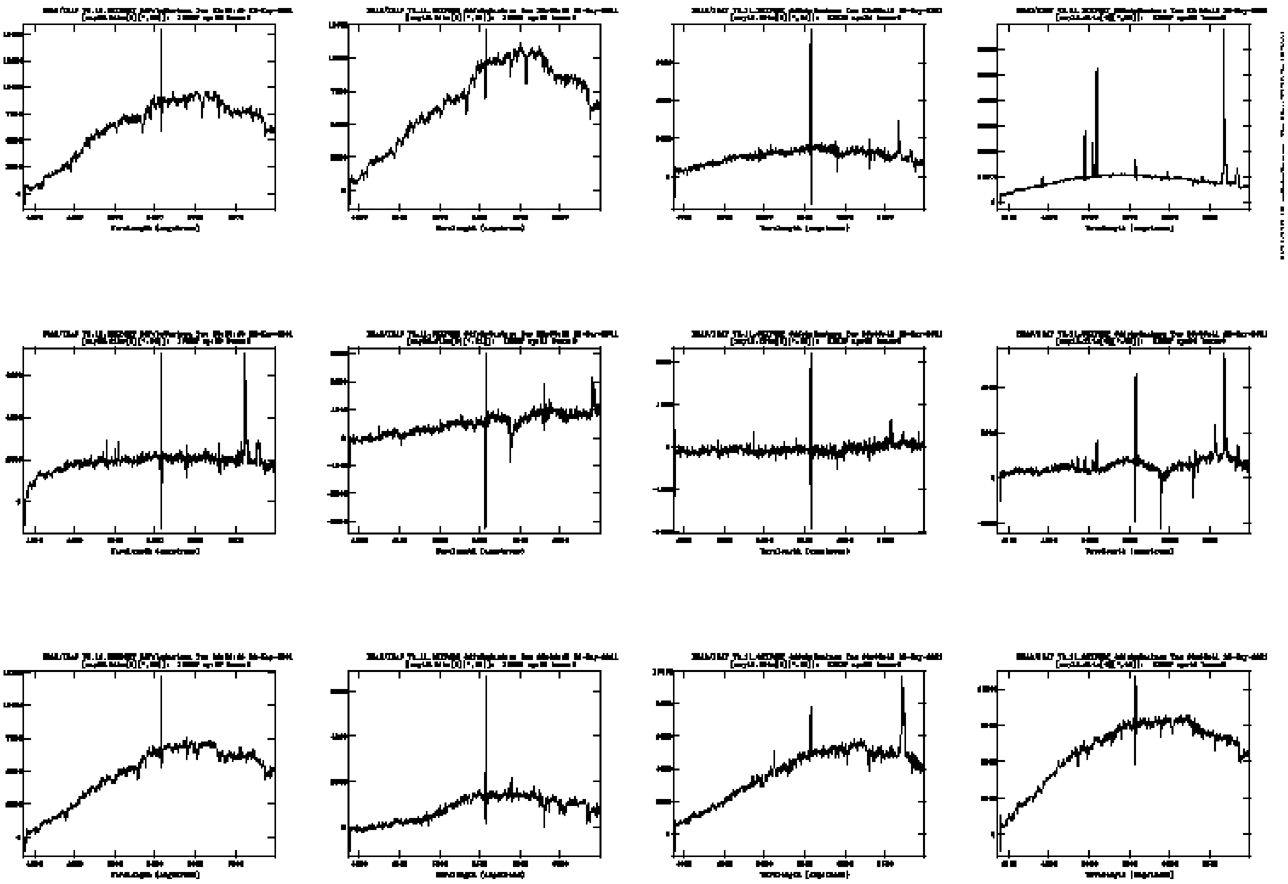

Figure 3. Reduced spectra from 12 successive target fibres, taken from the field in Figure 2. The feature near the centre of the spectrum is due to imperfect subtraction of the strong OI 5577Å sky line.

area of the 2dF strips.

In addition, 6dFGRS will include a large number (17!) of smaller target samples as follows:

- we will observe 15,000 nearby (<15,000km/s) early type galaxies to a higher signal to noise (25/A) to give accurate (10%) linewidths and hence, when combined with the 2MASS photometry, direct distance and peculiar velocity measurements. This is an order of magnitude larger than previous peculiar velocity surveys;
- we will observe additional sources as necessary to give complete samples of ~100,000 galaxies flux-limited at each of H and J (from 2MASS), also at J and I from the now completed DENIS survey (cdsweb.u-strasbg.fr/denis.html), and at r_F and b_J from the newly available SuperCOSMOS data (www-wfau.roe.ac.uk/sss);
- Additional targets solicited last year and selected by peer review have been defined: these include 10,000 2MASS-selected red AGN, 5000 optically bright ROSAT quasars and 3000 from the HES survey, and 10,000 IRAS FSS sources.

In total we expect to take 180,000 spectra. All sources will be observed, whether a redshift is known or not, to give a complete *homogeneous* library of high quality spectra. The first strip to be surveyed will be defined by 10h < RA < 20h, $-42° < \delta < -23°$, and $|b|>10$.

6dFGRS will utilise a new 580/mm VPH grating for the blue, and a 425/mm grating for the red, both working at the same collimator-grating-camera angles and hence giving the same $d\lambda/\lambda$ resolution. We aim to get *S/N*=10/A and *R*=1000 at 5500Å, with coverage from 3900 – 8300Å. Both *S/N* and *R* are significant improvements over 2dF, giving accurate (<50km/s) redshifts and allowing detailed studies of how clustering interacts with spectral morphology, linewidth, linestrength, metallicity etc. Over the next four years, 75% of UK Schmidt time is to be devoted to the survey. The data will be distributed via the Wide Field Astronomy Unit in Edinburgh (www.roe.ac.uk/ifa/wide_field.html) and will be non-proprietary.

Figure 4. The two proud commissioning scientists, Will Saunders and Quentin Parker

Non-survey Spectroscopy with 6dF

By December 2001, the UKST's remaining photographic surveys (the $H\alpha$- and *I*-surveys) will be essentially complete. It is expected that photography will then become a minor (<10%) part of the telescope's programme, being carried out only in the very best seeing. Except for small amounts of time that may be allocated to a yet to be implemented 1-degree-field CCD mosaic (an Australian National University/University of Tokyo collaboration), the main activity on the telescope will be 6dF spectroscopy.

The 75% of time devoted to the Galaxy Survey will leave some 15 - 20% available for non-survey spectroscopy, and this time will be allocated bi-annually through the normal Schmidt Telescope Time Assignment Committees. All AAO reflection gratings are available, as will be the new VPH gratings.

THE NEW EEV CCD

Chris Tinney & Ray Stathakis

EEV2, a 2k x 4k blue-sensitive CCD, saw its first action in April with the RGO Spectrograph. We found that EEV2 performs much as advertised by EEV/Marconi. It is a thinned, back-illuminated device with 15 mm square pixels, and offers unprecedented efficiency in the blue.

Read noises and gains as measured on the telescope are consistent with those measured by John Barton in the Epping labs. Linearity is similar to that measured by John and (unusually) is well corrected with a 'linear' alpha correction term. Dark current rates are low (<0.5e^-/1800s once the device has stabilised). The device has VERY nice cosmetics with low-level flat field structure in the blue, and just one hot spot and associated warm column. We measure an increase in efficiency of up to 40% over the Tek in the 4000–6000Å range. The cosmic ray hit rate is lower than for the MITLL devices. The only down side is extreme fringing, as expected with thinned devices. The fringes appear at the 0.5% level at 6500Å, but are ~60% peak-to-peak by 9000–10000Å.

Commissioning of the EEV with other AAT instruments will be undertaken shortly. More details on the commissioning tests can be found at http://www.aao.gov.au/local/www/cgt/ccdimguide/eev.html.