Extragalactic

Progress in Galaxy Redshift Surveys using FLAIR

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Abstract: Among the most important stimuli for developing the FLAIR multi-object spectroscopy system on the 1.2-m UK Schmidt Telescope was its potential for carrying out large-scale redshift surveys of galaxies of intermediate magnitude (B $<\sim$ 17). During FLAIR's lengthy development period, these objects provided the yardstick by which the system's performance was measured, and a number of limited-area redshift surveys were carried out. We are now following these with a 1-in-3 survey over the 60 fields of the ROE/Durham Galaxy Catalogue to produce a redshift map of some 4000 galaxies out to a distance of $\sim 300h^{-1}$ Mpc (where the parameter h is the Hubble constant expressed as a fraction of 100 kms^{-1} Mpc^{-1}). In this paper we summarise the results from our redshift surveys to highlight the capabilities of FLAIR. We present a status report on the current large-scale survey, and show that the recently-introduced FLAIR II system will speed its progress considerably.

1. Introduction

In 1984, when a multi-object spectroscopy system for the 1.2-metre Schmidt Telescope had yet to be completed, a paper was presented at the Annual General Meeting of the ASA outlining the new instrument and its anticipated role (Watson and Dawe 1984). While the general-purpose nature of the system was emphasised, its potential as a machine for undertaking large-scale galaxy redshift surveys was particularly highlighted. The determination of medium-accuracy ($\sim$ 60 kms^{-1}) redshifts for galaxies with a limiting magnitude of $B \sim 17$ was expected to be 'easily within the reach' of the telescope equipped with a fibre-coupled CCD spectrograph. This expectation indeed was eventually realised, but not without a substantial amount of development work.

The first prototype Fibre-Linked Array-Image Reformatter (FLAIR) for the Schmidt Telescope proved, in fact, to have deficiencies that rendered it unsuitable for galaxy redshift surveys (Watson 1988). It was not until the introduction in 1988 of major enhancements (collectively referred to as PANACHE — for PANoramic Area Coverage with High Efficiency) that serious pilot studies could begin (Watson, Oates and Gray 1990). PANACHE used 35 blue-transmitting, 6.7 arcsec (100 μm) diameter fibres fitted with input-end microprisms to allow positioning anywhere in the 40 deg^{-2} field of the telescope. With a blue-sensitised CCD and on-chip binning (for fibre-matching), PANACHE was optimised for spectroscopy of 17th magnitude galaxies. Although the overall sensitivity remained highest in the red, enough was gained in the blue to allow identification and measurement of the G-band and H and K lines of Ca II, all present in most galaxies.

In the three years following the introduction of the PANACHE upgrade, FLAIR was used to obtain spectra of some 2370 galaxies (compared with about 360 stars and 90 quasar candidates). Thus, the prediction (Watson and Dawe, 1984) that FLAIR's main stock-in-trade would be galaxy redshift surveys may be seen to have been borne out. While the total number of galaxies observed was quite substantial, it was limited by the modest number of fibre channels in the FLAIR/PANACHE system (so that only a fraction of the available galaxies in any given field could be sampled simultaneously). It is principally that limitation of the system that has been addressed with the development of FLAIR II, whose attributes are summarised at the end of this paper.

2. Limited-area Redshift Surveys

Following the improvements to FLAIR brought about by PANACHE, studies were carried out to quantify the capabilities of the instrument for galaxies of various classes and magnitudes. Since FLAIR was, by then, a common-user facility (operated in service mode) on the Schmidt Telescope, these were conducted by a number of authors on objects selected using a variety of criteria (e.g *IRAS* sources, candidate cluster or supercluster members, etc.).

Here we describe briefly only those surveys carried out by ourselves (which include the most substantial to date), and which involve galaxies selected only on the basis of integrated magnitude. Two limited-area redshift catalogues resulted from this work.

A preliminary study (see Watson *et al.* 1991, hereinafter WOSH) utilised 28 galaxies with previously determined redshifts (to $\sim$ 50 kms^{-1}) from the magnitude-limited ($b_J < 16.75$) catalogue of Peterson *et al.* (1986). It was found that with a dispersion of 98 Å mm^{-1} (yielding a CCD resolution of 4.2 Å pixel^{-1}), a series of four 3000^s FLAIR exposures produced, when summed, a signal-to-noise ratio of the order of six at 4000 Å for galaxies at the magnitude limit. This is sufficient to detect the H and K lines of Ca II, for example, and redshifts (to $\sim$ 150 kms^{-1}) were determined for 22 galaxies using these and other features, a success rate of about 80 per cent. The spectra of the remaining galaxies (generally late-type objects), while having adequate signal-to-noise, showed no strong features in the observed waveband ($\sim$ 3900 — 5150 Å).

This success rate was, for the most part, maintained in the observations carried out for a survey over nine standard Schmidt fields, also presented by WOSH. Using photometric data from COSMOS measurements of the target fields (MacGillivray and Stobie 1984), galaxies were selected for each field at the rate of 1-in-6 to a limit determined by the number of available fibres (usually 27, after sky and template galaxies had been accommodated). Thus, the magnitude limit varied from one field to another, the range being $16.63 \leq b_J(lim) \leq 17.01$. Of the 244 galaxies observed, 179 yielded reliable redshifts (using a criterion developed for the preliminary study which was based on the Tonry and Davis (1979) *r*-factor). The observations were made with the same instrumental configuration as before.

Although the nine fields of the WOSH survey were not all contiguous, some short strips were included to obtain a degree of continuous coverage. An additional field has since been observed to complete a seven-field strip from 12^h30^m to 14^h50^m along the equator (Hale-Sutton *et al.*, in preparation).

A different approach was taken by Parker and Watson (1990) in a magnitude-limited redshift survey of a single Schmidt field (ESO/SERC field 352, centred on 01^h12^m, -35° 00′). The resulting catalogue of 116 redshifts, containing 94 obtained with FLAIR and 22 from other sources, is about 75 per cent complete for $b_J < 16.5$. (Parker 1992, has recently extended the survey over seven Schmidt fields with 95 per cent completeness to $b_J = 16.5$, some 270 of the ~ 700 redshifts having been provided by FLAIR.)

For this work the same dispersion was used as in the WOSH study, but FLAIR spectra were obtained in the red (~ 5800—7050 Å) as well as the blue. This proved to be highly advantageous for galaxies in which Hα emission was present, since high signal-to-noise observations of the line could be made in a very short time (1800^s for objects with $b_J \sim 17$). The red exposures also offered the possibility of observing Na D in absorption, again at high signal-to-noise because of the relatively high overall sensitivity of FLAIR at 6000 Å.

An analysis was carried out of the accuracy of the FLAIR observations (Parker and Watson 1990); close agreement was found with WOSH in the estimated accuracy of the blue absorption-line velocities (~ 140 kms^{-1}), but it was also shown that ~ 60 kms^{-1} could be achieved using emission lines in the red. Given the rudimentary nature of the prototype spectrograph, this was a very satisfactory result, and highlighted the stability of the stationary, vibrationally isolated spectrograph mounting. It also underlined the desirability of accompanying blue observations with short exposures in the red to pick up any galaxies showing Hα emission.

3. The Present Large-scale Survey

The success of the preliminary surveys led to an initiative to undertake a long-term FLAIR project to map the 3-D galaxy distribution over a much greater area of sky (Shanks *et al.* 1989). Using, as a basic data set, the Edinburgh/Durham Galaxy Catalogue of Collins, Heydon-Dumbleton and MacGillivray (1988) obtained using the COSMOS measuring machine, the aim is to extend this catalogue to 3-D with a limiting magnitude of $b_J \sim 17$. The Edinburgh/Durham catalogue itself covers 60 standard Schmidt fields around the south galactic pole region (in four declination bands [-25° to -45°] of 15 fields each [~ 21^h30^m to 03^h30^m]). It is complete to $b_J \sim 20$ and contains ~ 10^6 galaxies. Our present Durham/UKST Galaxy Redshift Survey is of a random selection of these objects sampled at a rate of 1-in-3, and will result in a redshift map of some 4×10^3 galaxies to the FLAIR limit.

Enclosing a volume of space out to $300h^{-1}$Mpc from the Galaxy, the map will provide a true representation of the distribution of luminous matter by virtue of the high sampling-rate and the non-specific selection criterion. Direct inspection of structure on scales from 1 to $100h^{-1}$Mpc will be possible, so that the presence of such features as superclusters, filaments, sheets and voids will be readily apparent. In addition, the map will allow statistical analysis of the galaxy distribution over a wide range of scales. Investigations with a greater degree of sophistication than the simple 2-point correlation function will be possible, so that the nature of the galaxy distribution (e.g., 'sponge-like' or "bubble-like') may be explored (Shanks *et al.* 1989).

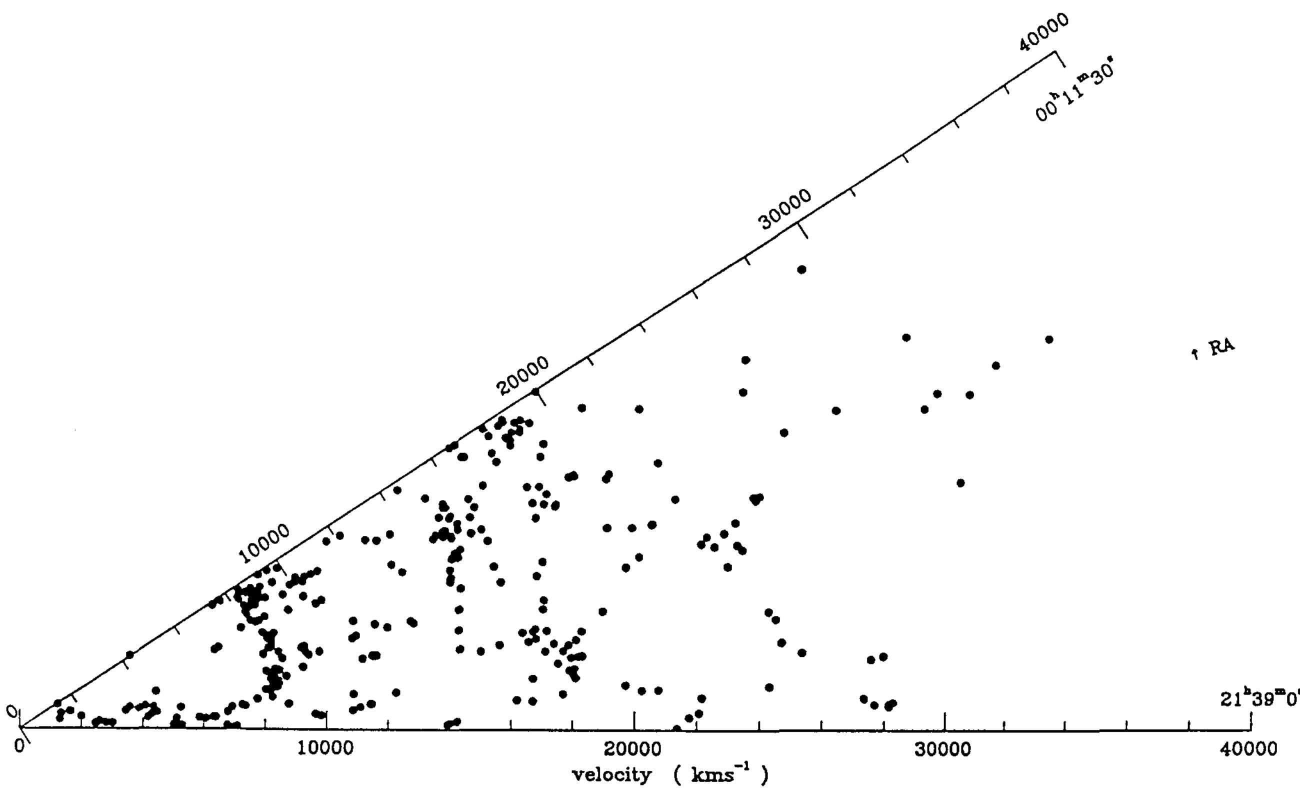

Figure 1 — Redshift distribution of 313 galaxies in the declination band -27°30′ to -32°30′. The galaxies were observed with FLAIR as part of the Durham/UKST Redshift Survey.

To the magnitude limit of the FLAIR survey, each Schmidt field contains about 200 galaxies, so that a sample of 60–70 objects per field is required. In order to facilitate the observation of all these objects with a single FLAIR set-up, an interim modification was made to PANACHE that allowed double the standard 35 fibres to be used. Because of the inexpensive nature of the prototype spectrograph, it was possible to duplicate it and thus run two 35-fibre feeds from a single plateholder (Watson, Oates and Gray 1990). The two sets of spectra were detected with two separate cryogenic cameras, each equipped with a blue-sensitised chip, but having common read-out and control electronics (Oates 1990).

By the end of 1990, despite generally poor weather, a total of seven Schmidt fields had been completed. Results from these are presented by Broadbent *et al.* (1991, 1992). Since then, another five fields have been observed so that the first declination strip is now nearing completion. Preliminary results from the first seven fields are shown in Figure 1, where the redshifts of 313 galaxies in the RA range $21^h39^m00^s$ to $00^h11^m30^s$ are plotted in a cone diagram. Already, a number of apparently strong features are emerging in the distribution.

The investigation of large-scale structure by means of optically selected galaxy redshift surveys is clearly a promising tool for cosmology, and is attracting attention from other workers in the field. In particular, Schectman (1992) is using a fibre-coupled multi-object spectroscopy system on the Las Campanas 2.5-m telescope to carry out a comparable survey. In order for the 1.2-m UK Schmidt Telescope to remain competitive — and for the Durham/UKST survey to be completed in a reasonable time — a substantial increase in observing efficiency is demanded; it is primarily this that has motivated the development of the FLAIR II system.

4. FLAIR II

The proposal to build a second-generation FLAIR system was made in 1988, and the project has proceeded largely with UK Science and Engineering Research Council funding and Anglo-Australian Observatory manpower. The new system was completed early in 1992.

The principal weaknesses of the FLAIR/PANACHE system were, first, the limited number of fibres imposed by the design of the prototype spectrograph and the rudimentary fibre-positioning arrangements; second, the waste of detector area — and consequent loss of resolution and spectral coverage — caused by the need to bin pixels on the chip; third, the poor blue performance of the spectrograph optics, and finally, the cumbersome plate-loading arrangements, which permitted the observation of only one field per night. In addition to these were several lesser problems, such as the outmoded computer system and software used to run the CCD camera, all of which contributed to less-than-perfect observing efficiency.

The design philosophy of FLAIR II was to develop the existing system to a level where these weaknesses were eliminated. Thus, for example, the proven technique of cementing fibre ferrules to a glass copy plate using optical alignment was retained, rather than attempting to build a fully automatic fibre positioner (which would have required a much more substantial budget).

The new system is described in detail by Watson *et al.* (1992), and Bedding, Gray and Watson (1992). At its heart is a new spectrograph that uses all-Schmidt optics, and allows a 20-mm slit length (compared with the 5 mm of the prototype) permitting the use of $92 \times 100\mu$m fibres. The spectrograph has improved blue performance and, with the detector properly matched to the fibres to eliminate the need for on-chip binning, has superior spectral coverage and resolution. Simultaneous imaging of the red and blue spectral regions referred to in Section 2 is now possible with 10 Å resolution, and early results show an overall improvement of $\sim 0^m.3$ in limiting magnitude for galaxy redshifts.

To accommodate the larger number of fibres, improved plateholders have been designed, with new features including retractable fibres. The provision of multiple plateholders and feeds, together with improvements to the telescope-loading procedure, will allow the possibility of observing two fields per night. A machine-vision computer-assisted fibre positioner (known as 'AutoFred') has been built to speed the reconfiguration of the larger number of fibres (Bedding, Gray and Watson 1992). 'AutoFred' senses the offset between the actual and required positions of a fibre, and automatically corrects it before cementing the fibre in place on the field plate. Thus, not only is more consistently accurate fibre-positioning achieved ($\sim 10\mu$m), but much of the burden of the manual set-up process is removed from the operator. It remains, however, a fairly labour-intensive process that demands a significant level of manpower during observing runs.

This aspect now seems likely to become the limiting factor in the rapidity of data-collection with the FLAIR II system. Potentially, with FLAIR II permitting the observation of two fields of ~ 90 galaxies each per night and with FLAIR time-allocations expected to increase from three to five nights per lunation, an improvement in the data-collection rate of up to ten times that of the original single-spectrograph PANACHE system is possible. Given the support of the time-allocation panels, and sufficient operating manpower, it is feasible that the Durham/UKST Galaxy Redshift Survey could then be finished in only a further two seasons.

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