SKY SURVEYS WITH THE UK 1.2m SCHMIDT TELESCOPE

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INTRODUCTION

On 1983 September 3 we will be celebrating the tenth anniversary of the formal hand-over of the UK 1.2m Schmidt Telescope (UKST) by the manufacturers, Messrs. Grubb Parsons of Newcastle-upon-Tyne, to the Science and Engineering Research Council (SERC). The completion of commissioning was marked in 1973 by the taking of the first completely successful sky-limited photograph on hypersensitised Eastman-Kodak IIIa-J emulsion, plate J149 of field 416. That plate itself led very quickly to exciting new scientific results, including the discovery of extraordinary and still apparently unique jets in the barred spiral galaxy NGC 1097 by Wolstencroft & Zealey (1975), a discussion of the clustering of 3000 faint galaxies (Dodd et al., 1975; 1976) and a suggestion that faint blue stellar objects are not randomly distributed (Hawkins & Reddish, 1975).

However, although that first plate had been obtained, it was to be another year before all the mysteries of plate hypersensitising, telescope guiding, focus control and plate processing were sufficiently well understood that good quality plates for the ESO/SERC Southern Sky Survey could be obtained routinely. Even now there are so many different faults which can spoil a survey plate that the success rate is only about fifty percent; the complicated quality control criteria are described by Cannon et al. (1978). Thus the early hopes of completing the survey in two or three years were not fulfilled, and in the end it has taken us just a decade to finish that job; perhaps this is one more instance where astronomical theory has had to be modified to fit new data!

Fortunately the 606 plates for the Southern Sky Survey do not represent anything like the entire ten-year output of the UKST; almost 9000 plates have been taken altogether and several other surveys are well underway, while special plates have been taken for several hundred research projects. In what follows I will describe the surveys and mention a few of the many discoveries which have been made, and say a little about future plans for the UK Schmidt.

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THE UK SCHMIDT TELESCOPE

The UK Schmidt is situated on Siding Spring Mountain in New South Wales, Australia, close to the Anglo-Australian 3.9m Telescope (AAT). However the two telescopes are operated quite independently, since the UKST belongs to the SERC and is run by a team of astronomers from the Royal Observatory, Edinburgh (ROE). The best source of up-to-date technical information on the UKST is the Schmidt Telescope Handbook, which has recently been completely revised and is available on request from ROE. Briefly, the telescope has an aperture of 1.24m and a focal length of 3.07m, yielding a plate scale of 67.1 arcsec mm^{-1} and a focal ratio of f/2.5. The photographic plates are 356mm square and each one covers a field of 6½° x 6½°. All of these parameters are identical to those of the older Palomar 48-inch Schmidt, and indeed the UKST was originally conceived as a copy of that famous telescope. However technological advances, together with a desire to exploit the new Kodak IIIa-J fine grain emulsion, led to a significantly enhanced optical and mechanical specification for the UKST. The result is that the main UKST sky surveys penetrate about 1.5 magnitudes deeper on average than the original National Geographic Society - Palomar Sky Survey.

There are a few special features of the UKST which deserve mention. Primary pointing accuracy, using a hand calculator version of the AAT program written by P.T. Wallace to correct for flexure and atmospheric refraction, is now ± 6 arcsec r.m.s. over most of the sky (a tenfold improvement over the design specification); all plates are taken using an autoguider (Adam, 1971) mounted on an auxilliary telescope, without which the success rate for long-exposure survey plates would be much lower; the polar axis elevation adjustment has been motorised so that it can be set to the optimum value to minimise field rotation for every exposure (Wallace & Tritton, 1979); the Schmidt corrector plate is a cemented achromatic doublet (Wynne, 1981), believed to be the largest such in the world, which gives ~ 1 arcsec resolution through the full photographic wavelength range from the atmospheric ultraviolet limit at 3200Å to beyond 10,000Å in the infrared; there are two full-aperture narrow-angle objective prisms which can be mounted separately or together on the telescope to yield reciprocal dispersions from 2400Å mm^{-1} to 600Å mm^{-1} at 4300Å; and there are several wide-field interference filters centred on astrophysically important lines such as H-alpha.

Innovations on the photographic side include automatic equipment for hypersensitising plates by a variety of techniques, the principal methods being soaking in nitrogen and then hydrogen gas at atmospheric pressure and at 20°C for IIIa-J and IIIa-F emulsions (Cannon et al., 1978), and bathing in dilute silver nitrate solution for IV-N emulsion (Hartley & Tritton, 1978); extensive sensitometric monitoring of every new batch of emulsion during hypering; stepwedge or spot calibrations which are put on to every plate during exposure in the telescope to facilitate the subsequent conversion of density or transmission measurements into intensities; and, most recently, the modification of the telescope plateholders to allow continuous flushing with dry nitrogen gas during exposure. This last feature prevents desensitisation of the hypered IIIa plates during exposure, and also results in better plate uniformity (Dawe & Metcalfe, 1982; and at this conference).

Making very high quality copies of original telescope plates on film or glass is essential for dissemination of Schmidt data in the form of sky atlases, and well-equipped laboratories have been established at ROE following the pioneering work of ESO in Geneva (now moved to Munich). The copying techniques have been described by Standen & Tritton (1979). There is a certain amount of friendly rivalry, and a lot of exchange of ideas, between the two establishments resulting from the perpetual struggle to maintain the highest standards. Some of the more specialised photographic techniques for image enhancement, such as high contrast printing and unsharp masking, will be described later by Malin and by Hadley.

Finally, and just as important for the successful exploitation of the UK Schmidt as a research telescope, we have set up plate libraries in Australia and Edinburgh which are well equipped with light tables, microscopes, Polaroid cameras and measuring machines. Astronomers are encouraged to come to Edinburgh in particular if they want to carry out research projects using UKST material. The system of the telescope together with the photographic laboratories and plate libraries is regarded as a 'national facility' for British university astronomers, but it is also very much an 'international' facility. By making originals and copies of plates freely available we are able to get much more astronomy out of the UK Schmidt Telescope than if each person simply kept his or her own plates, although individuals do have priority rights over plates taken especially for them for a limited period (up to two years), much as is the case for example with data from the IUE satellite. The operation of the telescope in Australia is in the hands of a team of half-a-dozen resident observers, and the telescope is run as a 'remote facility' even when not engaged in survey work. Thus astronomers are very rarely present when their plates are being taken. In these ways the telescope is able to support many more programmes for a much larger number of astronomers than if it was run as a 'common user' facility.

THE ESO/SERC SOUTHERN SKY SURVEY

The first major task of the UKST was to survey the southern sky from -17° to -90° declinations on Kodak IIIa-J emulsion. This set of 606 overlapping photographs comprises the SERC(J) half of the ESO/SERC Southern Sky Survey, covering the blue-green wavelength range from 3950Å to 5400Å. Complete sky coverage with good deep plates was achieved by 1980, although we are still trying to obtain top Atlas-quality plates for the last few fields. In fact a sort of equilibrium

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has now been reached, where we are having to replace the occasional survey plate because of accidental damage caused during copying or, more seriously, because of the problem of microspots or 'gold spot disease' (see Sim, this meeting).

Film copies of the ESO/SERC survey have been issued in instalments since 1976 to some 170 astronomical institutions; so far 507 fields have been issued. Glass copying has started more recently, also at the ESO headquarters in Munich. Ten sets are being made and up to now 180 fields have been issued. Added urgency has been given to this work by the requirements of the Guide Star Selection System at the Space Telescope Science Institute in Baltimore.

Numerous discoveries have been made on the SERC(J) Atlas photographs, and here I can give only a few examples. The most spectacular are very faint optical extensions discovered in nearby galaxies. For example, in NGC 1512 there is clear evidence for gravitational interaction with the companion galaxy NGC 1510 which has led to the formation of extensive but very faint spiral arms (Hawarden et al., 1979). In NGC 5291 an even larger scale phenomenon is seen: it seems that star formation, or rather dwarf galaxy formation, has recently been triggered over a region more than 100 kpc in extent (Longmore et al., 1979). The galaxy NGC 7531 (Cannon, in preparation) has a very low surface brightness companion. These, and the very peculiar galaxy NGC 1097 mentioned previously, are unique examples probably representing different physical phenomena. However, a whole new class of shell structure elliptical galaxies, possibly representing the aftermath of galaxy mergers, has been discovered by Malin & Carter (1983; Malin and Carter at this conference). Another fruitful type of object is represented by elliptical galaxies with dust lanes (Hawarden et al., 1981), the most spectacular example of which is the nearby radio galaxy NGC 5128 (Centaurus A). The latter has large scale optical extensions in approximately the same direction as the even larger radio lobes (Haynes, Cannon & Ekers, 1983). Turning to galaxies much closer to our own, the Carina dwarf spheroidal galaxy, which I discovered by chance on an SERC(J) survey plate (Cannon, Hawarden & Tritton, 1977), is the only new dwarf satellite of our own Galaxy to have been discovered in the last thirty years and brings the total number known up to seven.

I have concentrated in these examples on nearby galaxies, partly because this is work in which I have been involved, and partly because they make spectacular illustrations. However the SERC(J) survey has resulted in many new galactic discoveries such as the 'cometary globules' (Hawarden & Brand, 1976) and old planetary nebulae (Longmore, 1977; Longmore & Tritton, 1980). A systematic search for compact dust clouds has been carried out by Hartley, Hawarden, Manchester & Tritton (in preparation) and this has been followed up with radio studies of molecular absorption lines (Goss et al., 1980). On a much larger scale, very extended nearby filamentary material has been mapped out in the vicinity of the South Celestial Pole by King, Taylor & Tritton (1979) and foreground dust has been detected in front of many important galaxies and star clusters. The 'J' survey has also been used for many systematic survey-type extragalactic projects, such as searches for peculiar galaxies (Arp & Madore, 1977), for Seyfert galaxies (Fairall, this meeting), the classification of galaxies (Corwin, de Vaucouleurs & de Vaucouleurs, 1982), cataloguing clusters of galaxies (Corwin & Abell, in preparation), and the identification of radio sources (Savage, this meeting). At the other end of the distance scale, mention must be made of the considerable number of comets and asteroids which have been discovered on survey plates.

All of the above work has been done simply by visual inspection of the sky survey photographs. A whole new phase of Schmidt telescope astronomy is now under way using machine measurements of plates, particularly using the very high speed machines COSMOS in Edinburgh and APM in Cambridge. The accepted original sky survey plates are kept in a safe in an air-conditioned room in Australia, but little information is lost in making the copies. More importantly, a large stock of rejected but still very good quality sky survey plates is held in the Plate Library in Edinburgh. One project which relies on these rejected survey plates is the search for very faint variable objects, which is turning up substantial numbers of quasars and distant RR Lyrae stars (Hawkins, 1980; 1981; this meeting). Another machine-based project using direct survey plates is the study of the clustering and superclustering of galaxies (Shanks et al., 1980; MacGillivray & Dodd, 1980).

THE UKST EQUATORIAL SURVEY

Many of the discoveries on the SERC(J) survey, such as old planetary nebulae and faint star clusters, were qualitatively predictable in that such objects had been found on the Palomar survey and it was to be expected that similar objects awaited discovery in the southern sky. What is more surprising and exciting has been the discovery of some qualitatively new classes of objects, typified by the elliptical galaxies surrounded by shells and the 'cometary globule' nebulae. Presumably similar objects exist in the north but have not yet been noticed. The reason for these new discoveries is that the combination of the high-performance UK Schmidt Telescope with Kodak IIIa-J emulsion, and the very dark Siding Spring site, has allowed us to carry out a systematic survey reaching unresolved objects about four times fainter than the limit of the Palomar northern survey (done on much coarser-grained 103a-O emulsion). More importantly, the higher contrast of IIIa-J emulsion makes faint extended nebulosity much easier to detect; the new features typically have surface brightnesses of around 26 mag arcsec^{-2}. Even more can be extracted from these fine-grain photographs by using various contrast-enhancing techniques, as described by Malin and demonstrated by Hadley at this meeting, and features as faint as 28 mag arcsec^{-2} (corresponding to less than one percent of the background sky brightness) have been recorded.

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The upshot of these considerations is that it is obviously well worthwhile, now that the initial southern survey has been completed, to extend the IIIa-J survey northwards. Plans have been announced to refurbish the Palomar 48-inch Schmidt and repeat the northern survey. Since Palomar is at latitude 33°N while Siding Spring is at 31°S, it is very reasonable for the two new surveys to meet at the equator, and both telescopes will survey the 0° strip of sky to give a small area of overlap for comparison and cross-calibration. The UKST Equatorial Survey consists of 288 fields covering the zone from -18° up to +3° (i.e. plate centres at -15°, -10°, -5° and 0°) and is being done in two colours, using IIIa-J and IIIa-F emulsion. The optimum filter for the red (IIIa-F) survey is still under discussion. The original plan was to use the RG630 filter (cutting off at 630 nm), but this gives a rather narrow band since the emulsion cut-off is at 690 nm, and necessitates long exposures of up to two hours even on optimally hypersensitised plates. Tests are currently being carried out using an OG590 filter, giving a 70 percent increase in bandwidth. This should give almost as good an approximation to the standard photoelectric R band. The much narrower bandwidth had been chosen initially to give emphasis to H-alpha emission features, but this is no longer such an important consideration since the UKST is equipped with 80Å band interference filters centred on H-alpha (e.g. Elliott & Meaburn, 1976).

Originally the intention was to take pairs of blue and red photographs on the same night, as was done in the original Palomar survey, in order to minimise confusion between stars of extreme colour and variable stars. However, the much longer exposure times combined with the higher acceptance standards meant that the success rate for pairs of plates was unacceptably low. In any case, the Palomar survey already exists for this zone and will provide colour information on all but the faintest objects. Therefore the blue and red equatorial surveys are proceeding more or less independently, with the IIIa-J survey taking higher priority since these modern plates are again required for measuring Space Telescope guide star positions. Although the old Palomar Survey exists for this zone, the proper motions of potential guide stars are liable to be large enough that plates no more than ten years old are required to measure accurate offsets for Space Telescope targets. The current status of the Equatorial Survey is that Atlas-quality IIIa-J and IIIa-F plates have been obtained for 50 and 20 percent of the fields respectively; on-glass copying (four sets only) is already underway, and sets of Atlas film copies will be made in due course if there is sufficient demand from the astronomical community.

THE UKST NEAR-INFRARED SURVEY

The discovery that Kodak IV-N emulsion, although not designed as an 'a' series astronomical emulsion, could be hypersensitised by bathing in dilute silver nitrate solution (see Hartley & Tritton, 1978) led directly to its use on the UK Schmidt Telescope. It seemed

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particularly relevant for the UKST to carry out a near-infrared survey in view of the ROE's involvement in the UK 3.8m Infrared Telescope and British involvement in the IRAS satellite. Furthermore, such a survey could be carried in 'grey' time when the moon was up and so it did not conflict with the other major surveys. The survey involves taking pairs of plates, typically a 90 minute exposure on IV-N emulsion through an RG715 filter (covering the band 715 nm - 900 nm) and a matching 15 minute red exposure on IIIa-F emulsion through an RG630 filter. The first phase, now nearing completion, consists of 163 fields covering a band within ten degrees (plate centres) of the southern galactic plane plus the two Magellanic Clouds. Further details are given by Hartley & Dawe (1981). Some 70 sets of film copies of this Atlas are being made in the Photolabs at Edinburgh and distributed around the world; 140 fields have been issued so far. The Near Infrared Survey is now being extended to higher galactic latitudes. Rather little astronomical use seems to have been made of this survey so far, although Malkan et al. (1980) discovered one heavily reddened star cluster near the galactic centre. However, the latest reports from the IRAS group indicate that there are large numbers of new far-infrared sources to be identified and the 'I' survey may be particularly useful for this work.

OBJECTIVE PRISM WORK

A survey with the low dispersion (3/4°) prism (Nandy et al., 1977) was started several years ago as a low priority project. Most of the plates were taken in response to requests for specific fields. However there has been considerable discussion about the usefulness of such a survey. On the one hand there is no doubt that prism plates contain much more information than even a full set of broad-band direct plates, but only for stars or galaxies within a magnitude range of about two magnitudes and only to a plate limit some three magnitudes brighter (i.e. B ~ 19.5) than that of deep direct plates. It has also become apparent that, at least for visual inspection, the plates taken in the very best seeing are much more useful than the majority of the plates and that it would be difficult to carry out an all-sky survey to sufficiently high standards. When the new 2 1/4° prism became available (Cannon et al., 1982), it seemed desirable to compare its performance with that of the older prism before continuing with the survey. It is now clear that for some projects, such as identifying large samples of optical quasars, the low dispersion prism is greatly superior mainly because it reaches a fainter limiting magnitude. However perhaps the most effective argument against doing a large-scale survey is simply that it takes so long (several man-months) to scan a single plate, and that even then the results are best described as 'subjective' prism spectroscopy. A crucial new development has been the work of Clowes and his collaborators on the 'Automatic Quasar Detection' system (AQD) described by him at this conference. This uses COSMOS to scan prism plates and powerful computer software to analyse the data, which makes it possible to

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select large samples of quasars according to well-defined objective criteria; it also opens up the possibility of scanning larger numbers of plates and is causing a revival of interest in a large-scale prism survey.

Two important projects using the prism plates have been the selection of large samples of optical quasars, summarised for example by Smith (1983), and the confirmation of quasar candidates which had been selected as radio source identifications on direct survey plates by Savage (this meeting). The power of the Schmidt arises because it is not difficult to identify at least five quasars per square degree brighter than B magnitude 20, so that over 200 quasars can be found on each plate. This immediately makes it possible to find rare extra-ordinary quasars, and also permits some analysis of the clustering and possible alignment or association of quasars with other objects. However the powerful selection effects depending on magnitude, redshift and line strength have so far precluded the use of these visually selected samples for cosmological studies.

Quasars are of course not the only objects identifiable on the plates: the other $\sim 10^5$ images include interesting unusual types of star such as carbon stars (e.g. Mould et al., 1982), Wolf-Rayet stars and planetary nebulae (e.g. Morgan, 1983). Galaxies also give useful information; apart from the fairly obvious application to emission line galaxies, it turns out that even the low dispersion prism permits the determination of galaxy redshifts using the 4000Å feature to an accuracy of around 3000 km s^{-1}, for the study of super-clustering (Clowes, Cooke et al. and Parker et al., this meeting).

NON-SURVEY PROGRAMMES

In this review I have concentrated on the various sky surveys being done by the UK Schmidt Telescope. However no more than half of the usable telescope time is devoted to survey work. Frequently the seeing conditions are not good enough but still permit useful plates to be taken, especially for stellar photometry, or else the sky is bright so that only short exposure or interference filter plates can be taken. Even in 1973, when the SERC(J) southern survey had the highest possible priority, many special plates were taken for individual astronomers. Since then, and particularly since the high speed measuring machines became available, an increasing proportion of the best-seeing dark time has been used for non-survey work, so that recently about two-thirds of the plates taken each year have been for non-survey programmes. Altogether the UKST has supported some 600 programmes since 1973, with about 200 being 'active' at any time. Typically these programmes require only 2 or 3 plates each and requests are handled relatively informally on a 'first come, first served' basis by the UKST staff. Many such requests can now be dealt with by using existing plates from the ROE Plate Library or by providing copies made in the ROE Photolabs. However some programmes, such as the Manchester H-alpha survey of the Magellanic Clouds (Davies, Elliott & Meaburn, 1976), the University of California Asteroid Survey (Bus et al., 1982), searches for supernovae (Cawson, this meeting), faint variable stars searches, or studies of galactic structure, require larger numbers of plates and such programmes have to be approved by the SERC's Panel for the Allocation of Telescope Time.

Although our primary objective has to be the support of astronomical research in British Universities, we do our best to satisfy requests from astronomers in any institution in any country of the world, and at the most recent count about a third of our non-survey programmes involved foreign astronomers.

It would be unfair to describe any particular non-survey programmes among the hundreds which have been done; I hope that enough examples will be mentioned during the course of this conference to give an impression of the breadth and versatility of modern research which can be carried out with a large Schmidt telescope.

FUTURE PLANS

From what I have said above, a very simple arithmetical calculation will show that the present programme of the UKST will keep it more than fully occupied for another decade. However there is one *particular exciting new development on the horizon, which may* revolutionise our operation within the next few years. Preliminary experiments (described by Dawe here and Watson) are being carried out in Australia to use optical fibres in the telescope, in order to feed the light from many objects spread over the 40 square degree Schmidt field into a fast spectrograph with a modern electronic detector such as a CCD. This would free the Schmidt telescope from the limitations of the inefficient non-linear photographic plate, and make it directly competitive with much larger telescopes for many projects such as spectroscopy of clusters of galaxies or large samples of quasars. Indeed, it may make the concept of a really large new Schmidt-type telescope competitive with other proposals; a 2.5m Schmidt telescope with fibres could be as effective as a giant 7.5m telescope for many projects. However, no photoelectric detector comes close to matching the photographic plate in either resolution or number of picture elements, and so there will certainly be a long-term requirement for conventional photography as well.

Looking at the wealth of both 'expected' and unexpected results which have come from the UKST, both alone and in collaboration with the AAT, it is difficult to avoid the conclusion that a wide-field Space Schmidt telescope able to carry out a high resolution all-sky survey in the ultraviolet would be similarly successful, and would greatly enhance the effectiveness of the large Space Telescope. Such a proposal has been under discussion already for several years, starting with a NASA study followed by an unsuccessful ESA proposal.

Most recently, a group of astronomers at the University of Texas have been trying to set up an international project involving French, Italian, ESO and British collaboration. Unfortunately progress is slow at the moment, partly due to an international shortage of funds for astronomy and partly because of uncertainties over the best detector system to use. However there is an active IAU Working Group for Space Schmidt Surveys and further details can be obtained from its Chairman, K. Henize.

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