MAPPING THE SKY - SURVEYS WITH SCHMIDT TELESCOPES

D.H.Morgan and S.B.Tritton
Royal Observatory
Blackford Hill
Edinburgh EH9 3HJ
Scotland

ABSTRACT. This paper describes the sky surveys carried out over the past 30 years by the three large Schmidt Telescopes; the Palomar 1.2m Schmidt, the ESO 1m Schmidt and the UK 1.2m Schmidt. Developments in photographic technology, the reproduction of the surveys as sky atlases and problems associated with the storage of original plates are discussed. Brief reference is also made to limited purpose surveys which often address one specific research problem and to possible future developments in this branch of astronomy.

1. INTRODUCTION.

Much has been said about the value of sky surveys with Schmidt telescopes; see for example papers in the proceedings of IAU Symposium No 110, 'Astronomy with Schmidt-type telescopes'. In general, Schmidt surveys and related survey-style projects are essential for two kinds of astronomy: that which seeks to deal with the large-scale distribution of matter such as the distribution of stars within the Galaxy or the distribution of galaxies and quasars within the Universe, and that which deals with the selection of rare objects of special astrophysical interest. We will not attempt to repeat the earlier discussions on the value of sky surveys (e.g. Cannon 1984a) but instead will concentrate on some of the practical topics associated with the accumulation, reproduction and storage of sky surveys. We will also outline a few recent developments in the major surveys produced by the three large Schmidt telescopes: the 1.2m Palomar Schmidt, the 1.2m UK Schmidt and the 1.0m ESO Schmidt. Inevitably our direct experience with the UK Schmidt (UKST) will lead to a more extensive discussion of the work of that telescope.

2. SKY SURVEYS AND ATLASES.

Table I presents a summary of the major sky surveys – both those available as Sky Atlases and those in progress at the telescopes. In many ways the evolution of the surveys reflects the development of photographic emulsions. The introduction of the fine-grained Kodak IIIa- emulsions coincided with the construction of the two large southern Schmidts. Consequently, the ESO/SERC Southern Sky Survey is significantly deeper (~ 1.5 mag) than the older Palomar (Northern) Sky Survey. The increased depth available was one of the reasons for starting the new UKST Equatorial Survey and the new POSS-II survey. The effect of introducing fine-grained emulsions has

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TABLE I

Details of Sky Surveys (published and still in progress)

Survey	Colour	Dec Centres	N	Emul	Filter	Δλ nm	mag	Dates	Ref.
POSS-I	Blue	⩾ -30	935	103a-O	-	350-500	21	1950-58	1
POSS-I	Red	⩾ -30	935	103a-E	pg†	620-670	20	1950-58	1
POSS-I	IR	⩾ 0 *	80	IV-N	WR88a	770-900	19	1975-79	2
Palomar V	Visual	⩾ + 6+	583	IIa-D	GG495	495-620	19	1982-83	-
ESO-B	Blue	⩽ -20	606	IIa-O	GG385	385-500	21	1973-78	3
ESO/SERC	Blue	⩽ -20	606	IIIa-J	GG395	395-540	23	1974-87	4
ESO/SERC	Red	⩽ -20	606	IIIa-F	RG630	630-690	22	1978-	5
SERC-EJ	Blue	-15 -0	288	IIIa-J	GG395	395-540	23	1979-	4
SERC-ER	Red	-15 -0	288	IIIa-F	OG590	590-690	22	1984-	4
SERC-I/SR	IR	⩽ 0 *	163	IV-N	RG715	715-900	19	1978-85	6
SERC-I	IR	⩽ 0 #	731	IV-N	RG715	715-900	19	1980-	-
POSS-II	Blue	⩾ 0	894	IIIa-J	GG385	385-540	?	1987-	-
POSS-II	Red	⩾ 0	894	IIIa-F	RG610	610-690	?	1987-	-
POSS-II	IR	⩾ 0	894	IV-N	RG9	730-900	?	1987-	-

* *limited to galactic latitudes* $|b^{II}| < 10^\circ$; *matching short exposure red plates are included in the Atlas. The SERC-I/SR also includes the Magellanic Clouds*

\+ *Although this survey was not published it is included because machine measurements are available on optical disks at the Space Telescope Science Institute*

\# *limited to galactic latitudes* $|b^{II}| > 10^\circ$.

† *no. 2444 red Plexiglass filter.*

Notes:

(1) SERC surveys are those taken with the UKST
(2) The POSS-I and Palomar V are on field centres spaced at 6° *intervals. All other surveys are on* 5° *centres*
(3) The POSS and SERC field sizes are $6\overset{\circ}{.}4 \times 6\overset{\circ}{.}4$; *the ESO field size is* $5\overset{\circ}{.}5 \times 5\overset{\circ}{.}5$
(4) N is the number of fields in the survey
(5) Δλ is the nominal waveband for each survey but is not defined in a consistent manner
(6) mag is the nominal limiting magnitude
(7) the dates refer to the original survey plates

References: (1) Minkowski and Abell (1963), (2) Hoessel et al. (1979) (3) West and Schuster (1982), (4) Cannon (1984a), (5) West (1984), (6)Hartley & Dawe (1981).

been well illustrated by Cannon (1984b – his Fig 3). A similar illustration is provided in Fig 1 showing the ESO–B (60 min exposure on IIa–O) and SERC–J (60 min exposure on IIIa–J) images of a spiral galaxy in Field 444. Another interesting comparison is between the red half of the ESO/SERC Southern Sky Atlas (obtained with the ESO Schmidt) and deep red plates taken with the UKST using the same filter–emulsion combination. This is also shown in Fig 1 and is representative of many fields. The plates are very similar in quality and depth with the ESO plate being fractionally deeper for stellar images but slightly less deep for galaxies and faint nebulosity. These differences are primarily due to the generally superior seeing at La Silla and the different focal ratios of the two telescopes.

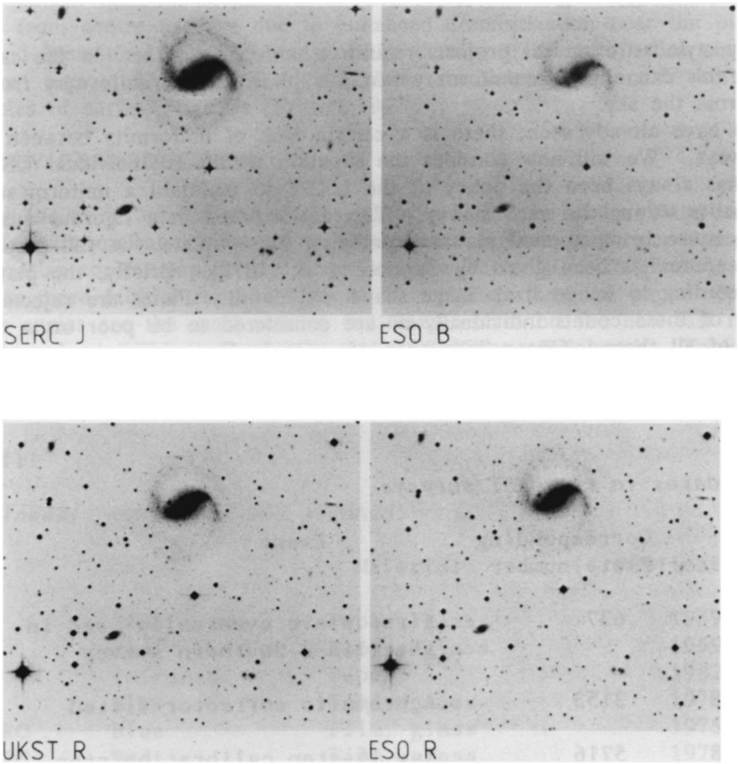

Figure 1. An area of Field 444 as seen on the ESO B, SERC J and ESO R sky survey film copies. The UKST R print is from a deep red plate obtained with the UKST.

It is apparent from Table I that the sky surveys are by no means uniform in waveband. The filters selected for the various surveys were chosen for diverse reasons. For example, after starting the UKST Equatorial survey with an RG630 filter (as used by ESO) it soon became clear that changing to an OG590 filter would result in a much speedier completion of the survey. This improvement in

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speed would be due, not only to the shorter telescope time required to obtain each plate, but to a decrease in the plate rejection rate. By being in the telescope for a shorter period, the plates suffer from less deterioration of image size and are subject to smaller amounts of image trail caused by field rotation, guiding inaccuracies and atmospheric refraction. The resulting 'OR' band is close to the photometric R–waveband; but the sensitivity of the plates to Hα emission is reduced. This could be important for the detection of emission line nebulae, though these objects are usually seen on IIIa–J plates through [OIII] emission. However, it is important to note that nebulae are much fainter on IIa–O plates due to the bluer cutoff of that emulsion.

3. SURVEY UNIFORMITY.

Most survey–style astronomical projects require a uniform data set. In the case of sky surveys this can apply to uniformity across a plate and to uniformity from plate to plate across the sky.

As we have already seen, there is a certain lack of uniformity between the various surveys. We will now consider the situation within an individual UKST survey. It has always been the policy of the UKST to maintain a uniform standard of plate quality throughout each survey. This has resulted in a rigorous quality control procedure being applied to every potential survey plate. A full description of this procedure has been given by Cannon et al. (1978). Briefly, the plates are assessed according to image size, image shape and depth. Plates are rejected if they fail on any of these counts individually or are considered to be poor on a cumulation of all three. One consequence of strict quality control is the prolongation of the time needed to complete a survey.

TABLE II

Important dates in the UKST surveys

Date	Corresponding Plate number	Event
1974 Jun 17	637	First plate eventually used in the IIIa-J Southern survey
1977 Apr 28	3153	Achromatic corrector fitted
1980 Feb 28	5716	New 16-step calibration step wedge fitted permanently
1982 Jun 11	7794	New processing line introduced for IIIa-emulsions only: normal fix replaced by rapid fix
1982 Dec 3	8271	Nitrogen flushing of IIIa-plates routinely used during exposure

Yet even with strict control, the survey quality changes with time due to both natural and introduced causes. For example, the period of the UKST Southern Sky Survey (1974–1987) has seen one complete solar cycle and the subsequent changes in sky brightness and survey limiting magnitude: the early plates and the most recent plates can penetrate deeper than those taken around 1980–1982. Again in the case of the UKST, several hardware changes have been made during the survey period. These are listed in the UKST Handbook and some are given in Table II. It is probably true to say that changes within the Equatorial survey period will be fewer. It is also true to say that the most dramatic mid–survey change was the introduction in 1982 of the nitrogen flushing of plates in the plateholder during exposure. Before that time IIIa– plates taken in conditions of moderate or high humidity were far less uniform than those taken in low humidity, showing exaggerated density gradients from centre to edge due to enhanced desensitization near the plate edges (Dawe and Metcalfe 1982). A study of the density gradients of atlas plates has shown that copies of post–1982 original plates are indeed very much more uniform than copies of earlier originals (Tritton 1987).

4. SURVEY REPRODUCTION.

A survey has to be copied and distributed in order to be of maximum use to the worldwide astronomical community. Three materials have been used for published negative Atlas copies: paper, film and glass (see Table III). In general, the film copies are more faithful reproductions of the originals than the paper copies, while the glass copies are the most suitable for measurement on the new fast measuring machines such as APM at Cambridge and COSMOS at Edinburgh. Table III gives details of all the Sky Atlases including estimates of future publications. It is hoped that the whole sky will be available on film in both red and blue within ten years.

TABLE III

Sky Atlases; published and planned

Survey	Colour	Material	Publication period	
POSS-I	Blue	Paper, glass	1959-1963	
POSS-I	Red	Paper, glass	1959-1963	
POSS-I	Infrared	Paper	1982-1982	
ESO-B	Blue	Film, glass	1972-1975	
ESO/SERC	Blue	Film, glass	1975-1988	
ESO/SERC	Red	Film, glass	1978-1990	?
SERC-EJ	Blue	Glass	1984-1990	
SERC-EJ	Blue	(Film)	1988-1992	
SERC-ER	Red	(Film)	1992-1995	?
SERC-ER	Red	(Glass)	1995-1999	?
SERC-I/SR	Infrared	Film	1982-1985	
SERC-I	Infrared	(Film)		?
POSS-II	Blue	(Film, glass)	1990-1996	
POSS-II	Red	(Film, glass)	1990-1996	
POSS-II	Infrared	(Film, glass)	1990-1996	

The brackets refer to future productions.

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Copying survey plates for reproduction is by no means a trivial business. Many years experience have gone into the work of the photographic laboratories at ESO and at the UKST. Details of copying procedures have been given by Standen and Tritton (1979) and by West (1978). Copying often introduces spurious images; and flaws or dirt on emulsions can cause slight but detectable defocussing. Hence strict quality control of all copying is also necessary. Some of the problems encountered by the ROE Photolabs have been described by Roberton and Tritton (1987).

5. STORAGE OF SKY MAPS.

It is important to maintain a photographic plate archive that will store plates with minimum deterioration over many years. The most obvious purpose in storing plates is to maintain a dataset for comparison with a similar one at a later epoch in order to measure proper motions. The storage facilities of the Plate Library at Edinburgh provide a compromise between an archive store and a working plate inspection environment (for details see Cannon (1984c)). Most UKST original survey plates are kept in similar conditions at Siding Spring Observatory.

The subject of storage has become very important recently following the discovery of microspots on IIIa–J, IIIa–F and IV–N emulsions. These spots can very quickly spoil a plate stored carefully for many years. A full account of this problem is given by Good and Gourlay (1984) and by Good (1987). It is hoped that the change introduced into the plate processing line at the UKST in 1982 (see Table II) will eliminate the problem. Nevertheless, the process of selenium toning all older UKST IIIa– plates as recommended by Kodak (Lee et al. 1984) is being implemented and is expected to produce long–lasting images.

Since most modern astronomical uses of surveys require the measurement of the plates and since long–term photographic plate storage is still rather uncertain, the alternative procedure of measuring a whole sky survey and storing the data on optical disk becomes very attractive. This process is already underway in the case of glass copies of the IIIa–J half of the ESO/SERC and SERC–EJ Sky Atlases. A catalogue of all objects in these surveys measured on COSMOS down to $B \sim 22$ has already been started (MacGillivray et al. 1987). Other similar projects are also underway (see for example Lasker, this meeting).

6. LIMITED PURPOSE SURVEYS.

There are many astronomical projects that require large area or all sky coverage in order to search for or to map unusual or special kinds of object. Some of these projects can use published sky Atlas material (see, for example, Cannon 1984a), but many need special sets of plates which fortunately do not necessarily require the optimum sky conditions used for the sky surveys. The philosophy behind the operation of the UKST has been to devote a large fraction of the telescope time (~ 60 %) to small research projects and to special large survey–style projects. Many surveys carried out on smaller Schmidt telescopes fall into this category but are too numerous to describe here.

Three UKST survey projects illustrate the range of special surveys made over the years. First there is the low dispersion objective prism survey. Since many projects can use this material, we routinely copy all survey quality prism plates. To date we have accumulated 97 plates that may form the basis for a published Prism Sky Atlas at a later date. One of the main uses of this material is the detection of quasars and the study of their 3–dimensional space distribution. Initially a painstakingly slow procedure by eye, this work is now done using fast measuring machines and produces ~ 5–6 'high-quality' quasar candidates per square degree (Clowes et al. 1987). The second is the Hα survey of part of the Galactic Plane and the Magellanic Clouds (e.g. Davies et al. 1976). The plates were taken through a special narrow-band filter and reveal Hα-emitting stars and nebulae very clearly. The third survey project is the ultraviolet survey for blue objects. Machine measurements of U and B images, either on single plates or, in the case of the UKST, on pairs of plates, can reveal all objects that are unusually blue. This technique has been applied in the northern hemisphere (Green et al. 1986) using a small Schmidt and is being extended to southern skies by Demers et al. (1986) to B=16–17 again using a small telescope, and by Stobie et al.(1987) using the UKST but to a deeper limit of B=18. Deep ultraviolet sky surveys are at present unrealistic because sky limiting U plates require a large amount of telescope time (e.g. 3–4 hours on the UKST). Deeper multi-colour surveys are under way using the UKST but on progressively smaller areas.

7. FUTURE SURVEYS

The three large Schmidt telescopes are heavily committed to survey work in the foreseeable future: the Palomar Schmidt has just started the second northern sky survey which will dominate its output for most of the coming decade; the two southern Schmidts have red surveys in progress; and the UKST infrared survey (for which plates can be taken in grey time) will not be completed for many years.

There is currently much discussion about a second epoch survey to be carried out using the UKST. The earliest IIIa-J survey plates are now about 15 years old and, due to proper motions, present considerable problems for the Space Telescope guide star programme. This time base is also adequate for certain astrometric programmes involving proper motions. No decision has yet been taken as to whether a second UKST southern survey should be carried out in the red or in the blue.

However, the future of all surveys lies very much with the manufacturers of photographic plates. When a new generation of spectroscopic plates becomes available, probably through the new Kodak T-grain emulsion (Malin 1984), new information will be attainable on sky surveys particularly if the new emulsions show improvements in resolution (Cannon 1984b). A gain of one magnitude will reveal many new objects in the sky maps and will improve the signal-to-noise of images in the B=21–23 magnitude range just detectable on the IIIa- emulsions.

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Discussion:

HEMENWAY Do you have any accurate information about the difference between the dimensional stability of the film compared with the glass copies?

RUSSELL Brian McLean and I did an experiment where we measured a glass copy and a film copy made from the same original plate. We reduced one to the other and noted a systematic trend in the residuals. The trend was about one and a half cycles across the plate and had a maximum of 16 micrometers. We have not measured the original yet and so do not know for sure if the error is in the film copy, although we have assumed it is.

LASKER I am pleased to use the forum of this Symposium to note the gratitude of the Space Telescope community to the UKSERC for furnishing a preliminary version of the Equatorial J Survey in time to prepare the Guide Star Catalogue and to support the launch of the Space Telescope. To follow this with a question, would you please elaborate on the film-glass issue?

TRITTON Glass atlas plates cost about 10 times more to produce (and to buy) than film copies. The requirement for glass plates comes from the large automatic measuring machines. It would be nice to know if the film copies are as stable as the glass plates for position measurements.

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