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MAJOR SURVEYS AND ARCHIVING

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Sky Surveys and Atlases from the Large Schmidt Telescopes

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Abstract. This paper describes the major sky surveys carried out with the large Schmidt telescopes and the sky atlases made from them. It also describes some of the science which has come from them and notes the importance of this work in almost every branch of astronomy.

1. Introduction

Sky surveys have underpinned a large fraction of astronomical research for many years. By providing simple visual maps of the sky at high resolution they are used by astronomers working at wavelengths from the radio to X- and γ-rays. Although they have been made for over 40 years, they are now at their greatest level of production at the telescopes and in the copying laboratories. The advent of accurate and fast measuring machines over the last 10 years or so has dramatically increased their value. During this period there have been several conference review papers on surveys and related topics: Cannon (1984) concentrated on the scientific importance of surveys, Morgan & Tritton (1988) reviewed survey progress, Morgan et al. (1992 – MTSHC) updated the 1988 review and also described the science coming from the special research projects underway on the UKST, and Hartley (1994), in last year's IAU Symposium in Potsdam, reviewed the subject of photography in general. In what follows I will concentrate on the work of the UK 1.2 m Schmidt Telescope (UKST) in Australia which was operated by the Royal Observatory Edinburgh (ROE) until mid-1988 and, since then, by the Anglo-Australian Observatory (AAO) ; but much of what is said will apply in general terms to the work of the other large Schmidt telescopes involved in survey work: the ESO 1.0 m in Chile and the Palomar Oschin (48-inch) 1.2 m in the USA.

2. Sky Surveys

In general, sky surveys involve the systematic photographing of large areas of the sky in single wavebands, and more often than not these surveys are subsequently copied and distributed as sky atlases. It is difficult to distinguish between the obvious sky surveys and large, special projects of a survey kind; some of the latter are extensive enough to be called surveys in their own right and are discussed in §2.2.

2.1. Major Surveys

At least fourteen major sky surveys have been completed by or are still in progress at the three large Schmidt telescopes. These surveys are summarized in Table I.

TABLE I Details of Sky Surveys completed or still in progress

Survey	Dec centres	N	Emul	$\Delta\lambda$ nm	Dates	Comp %	Ref
POSS-I	$\geq$ -30°	ϕ935	103a-O	350–500	1950–1958	100	1
POSS-I	$\geq$ -30°	ϕ935	103a-E	620–670	1950–1958	100	1
POSS-I	$\geq$ 0° *	ϕ80	IV-N	770–900	1975–1979	100	2
ESO-B	$\leq$ -20°	ψ606	IIa-O	385–500	1973–1978	100	3
SERC-J	$\leq$ -20°	606	IIIa-J	395–540	1974–1987	100	4
ESO-R	$\leq$ -20°	ψ606	IIIa-F	630–690	1978–1990	100	5
SERC-EJ	-15° – 0°	288	IIIa-J	395–540	1979–	99	4
SERC-ER	-15° – 0°	288	IIIa-F	590–690	1984–	84	4
SERC I/SR	$\leq$ 0° *	163	IV-N	715–900	1978–1985	100	6
SERC-I	$\leq$ 0° ‡	731	IV-N	715–900	1980–	44†	–
AAO-R	$\leq$ -20°	606	IIIa-F	590–690	1990–	62	7
POSS-II	$\geq$ 0°	894	IIIa-J	385–540	1987–	75	8
POSS-II	$\geq$ 0°	894	IIIa-F	610–690	1987–	78	8
POSS-II	$\geq$ 0°	894	IV-N	730–900	1987–	34	8

Notes: (1) the SERC- and AAO- surveys are taken with the UK 1.2m Schmidt Telescope, the ESO- surveys are taken with the ESO 1.0m Schmidt Telescope, and the POSS- surveys are taken with the Palomar Oschin 1.2m Schmidt Telescope, (2) N is the number of fields in the survey, (3) $\Delta\lambda$ is the nominal waveband for each survey but is not defined in a consistent manner, (4) the dates are those of the first and last original survey plates, (5) the 'Comp' column gives the appropriate level of completeness at 1.1.94.
ϕ 6.5° non-overlapping fields on centres spaced 6° apart.
ψ 5.5° non-overlapping fields on centres spaced 5° apart.
Other surveys are 6.5° fields on centres spaced 5° apart with significant overlaps.
* limited to galactic latitudes $|b^{II}| < 10°$; matching short exposure red plates are included in the Atlas. The SERC-I/SR Survey also includes the Magellanic Clouds.
‡ limited to galactic latitudes $|b^{II}| > 10°$ and excluding the Magellanic Clouds.
† 64% completed to B-grade level.
References: (1) Minkowski & Abell (1963), (2) Hoessel et al. (1979), (3) West & Schuster (1982), (4) Cannon (1984), (5) West (1984), (6) Hartley & Dawe (1981), (7) Morgan et al. (1992), (8) Reid et al. (1991).

There are a few changes from a similar table presented by MTSHC. Table 1 (above) includes completeness levels for the surveys at or near the start of 1994. The POSS-II and AAO-R Surveys have been proceeding quickly but the SERC-ER and more so the SERC-EJ Surveys have been advancing rather slowly. This is normal for survey production (the last 1% of the POSS-I Survey took $2\frac{1}{2}$ years - Reid & Djorgovski 1993): some seasons are less reliable for acquiring plates due to a combination of poorer weather conditions and short nights; also, once several almost acceptable plates have been obtained for a given survey field - as they will for some fields - observers tend to proceed with competing surveys

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unless the sky conditions are especially good and an acceptable plate is almost guaranteed.

Inter-survey comparisons have already been made. Those on modern emulsions are, of course, deeper than the older 103a- and IIa- surveys (Morgan & Tritton 1988) but are themselves similar in depth: the ESO-R is comparable with the the AAO-R (or equivalent plates) (Morgan & Tritton 1988), and the SERC-J and POSS-II J Surveys are similar in depth (Hartley 1994).

The recent announcement by Kodak that they are unable to continue to manufacture IV-N plates beyond the next few years causes a serious problem for the very important I-Surveys. It remains to be seen whether complete sky coverage can be attained and, if so, to what degree of uniformity this is possible.

2.2. Minor Surveys

There are currently three minor surveys being carried out with the UKST: the Edinburgh-Cape Blue Object Survey, the UKST Low-Dispersion Objective Prism Survey, and the UKST Magellanic Clouds Multicolour Survey.

The Edinburgh-Cape Blue Object Survey involves taking medium-depth plate pairs in the U and B wavebands on 380 ESO/SERC standard fields in the southern sky at galactic latitudes $|b| \geq 30°$. It is described in more detail by Stobie (these proceedings).

The UKST Low-Dispersion Objective Prism Survey consists of unfiltered, sky-limited, IIIa-J plates taken on standard ESO/SERC survey centres through the 2400 Å/mm dispersion objective prism (Savage et al. 1985). Most of these plates were taken as a direct response to requests from astronomers for specific research purposes, but top quality plates have been copied and then stored as survey master originals. To date, $\sim 10\,\%$ of the southern sky has been covered.

The Magellanic Clouds Survey is designed to obtain sets of plates in several colours of the Large and Small Magellanic Clouds, to copy these, and to sell film sets for use as research material. The colours included are U, B_J, V, R (full depth and short exposure) and I; low-dispersion objective prism plates will be available as well. Twelve fields are being covered; they are ESO/SERC fields 28-29, 32-33, 50-51, 55-57 and 84-86. The films will be sold as sets of twelve in each of the individual colours. The I, SR and R sets are already available as film copies, but the other sets have still to be completed.

Mention should also be made of the 'Quick V' (Lasker et al. 1990) and Proper Motion Surveys (Luyten 1963) made with the Palomar Observatory Schmidt Telescope. The former was taken for the HST Guide Star Catalogue but is not generally available.

2.3. Survey Uniformity

Any survey must be uniform if it is to be useful for projects which compare one area of sky with another (e.g., galaxy clustering maps) or if a specific depth is expected (e.g., the non-detection of a radio or X-ray source should be quantitative to a certain level). However, perfectly uniform surveys are impossible to achieve and a balance between desirability and practicability needs to be set. In the case of the UKST surveys, all plates are graded according to image size, image shape and overall depth (see Cannon et al. 1978 for details). Plates are rejected if they fail on any of these counts individually or are considered to be

poor on a cumulation of all three. Similarly, a certain level of emulsion flaw must be tolerated. Acceptable survey master plates are generally graded 'A'; an alphanumeric code describes the precise qualities of the plates. Knowledge of these grades is particularly important when using survey material in a quantitative manner.

Yet even with strict control, survey quality changes with time from both natural and introduced causes. For example, the period of the UKST Southern Sky Survey (1974–1987) has seen one complete solar cycle and subsequent changes in sky brightness and survey magnitude limit. More recently, the large quantities of dust from the Mt Pinatubo eruption have also affected the sky brightness and subsequently the survey depth of both UKST and POSS-II surveys (Savage, private communication, Reid & Djorgovski 1993).

Hardware changes or modifications also occur from time to time. The most significant change at the UKST has been the introduction in 1982 of flushing the plateholders with nitrogen during exposure (see the UKST Handbook for details). Plates taken since 1982 are known to show smaller density gradients, much closer to the telescope's vignetting function.

Another problem for surveys and wide-field imaging in general is that of trails caused by satellites and other fast moving objects. Statistics of satellite trails on $\sim$ 1000 UKST IIIa- Survey plates have been obtained and analysed (Fosbury et al. 1992). Some badly affected plates show 10-15 satellite trails. The analysis shows that contamination is greatest near twilight and remains non-zero even towards midnight. Moreover, the numbers of unaffected plates are decreasing. For the SERC-J and -EJ Surveys combined, 53 % of the $\sim$510 plates taken before 1980 are without a satellite trail, whereas only 30 % of the $\sim$ 320 plates taken since 1980 are unaffected. The average number of trails per plate has almost doubled from 1.1 for pre-1980 plates to 2.1 for post-1980 plates. Manmade satellites are not the only offenders: Figs 1 and 2 show a spectacular fireball appearing to issue from the spiral galaxy NGC 253.

3. Survey Accessibility

The usual means of access to the data contained in the Sky Surveys is through Atlas copies. The alternative is by loan of original plates from the Observatory holding the survey.

3.1. Sky Atlases

Most astronomers have access to survey material through the atlas sets which have been made from the original plates and sold worldwide. Copies have been made at CalTech for the older POSS-I surveys and at ESO and ROE for the newer atlases. Three materials have been used: paper, glass and film. In general the paper copies do not give such faithful reproduction as the glass and film copies and have not been used for atlas production for many years. Film copies are the best for visual inspection purposes and glass copies for machine measurement. The ROE Photolabs are now primarily engaged in making copies of the SERC-EJ Atlas on film and the SERC-ER Atlas on glass. Production of film copies of the SERC-ER Atlas will start when the SERC-EJ Atlas on film is completed. The ESO Sky Atlas Laboratories are engaged in the task

of copying and distributing the POSS-II Survey as the PO-ESO Photographic Atlas of the Northern Sky. See MTSHC for details of the published Sky Atlases and estimates of future publications.

3.2. Plate Libraries

In general, original survey plates accepted as masters for the sky atlases are not available for loan to the astronomical community. However, in the case of the UKST, the original master plates of the SERC-ER and SERC-I Surveys are available for measurement and digitization on the UK's own fast measuring machines until glass copies are made. The same is true for the AAO-R Survey, but those plates are also being measured at the Space Telescope Science Institute, and glass copies are not due to be made.

Most survey fields also have slightly inferior B- and C-grade originals. The ROE Plate Library does let these out on loan for special approved projects. They can also be used in conjunction with survey A-grades to improve the photometric accuracy of machine measurements though the sets of fields for which this can be done are by no means homogeneous. For the southern hemisphere IIIa-J surveys (SERC-J and -EJ), 32% of the 894 fields have 1 plate, 23% have 2 plates and 45% have 3 or more plates, and for the southern hemisphere I surveys (SERC-I and -I/SR), 45% of the fields have 1 plate, 32% have 2 or more plates and 23% are still without a plate. These numbers include all full exposure plates on the standard field centres.

3.3. Microspots

One of the most disappointing aspects of modern emulsions is their propensity to develop microspots. These microspots are small spots usually of a yellow or gold colour and commonly with a mirrored surface; they render the affected areas unusable for many purposes, and, since they often preferentially affect the calibration wedges, make the use of the whole plate difficult. Although certain processing techniques seem to inhibit microspot formation, many plates are affected. For the most recent statement about microspots on UKST plates see Tritton et al. (1994).

4. The Scientific Use of Surveys

Schmidt telescopes are important research tools in their own right, and consequently the UKST has devoted much telescope time to 'non-survey' projects, usually when sky conditions are unlikely to produce survey A-grade plates; much of this work has been channelled to the UK's two fast plate measuring machines, APM and COSMOS.

It is natural to ask whether it is the surveys or the special projects that give the best scientific returns for the telescope time invested. If it is the latter, then should the large Schmidts be devoted entirely to project work? The relative advantages of the two approaches are as follows: surveys - very large area coverage, as uniform observing conditions as possible, as deep as possible with a single plate; special projects - full choice of many wavebands, increased depth through multiple plates, choice of field centres, time-dependent exposures.

Thus, whilst ideal for some projects such as all-sky galaxy catalogues, surveys are very limited for others.

4.1. The Example of Quasars

The existing surveys cannot be used for identifying low redshift ($z < 2$) quasars - a U plate is needed; nor can they be used to detect very high redshift quasars ($z > 5$). For today's 'high redshift' quasars ($z \sim 3$–5), the sky surveys are not especially deep because they include the relatively shallow I-waveband; yet it is here that they have been most influential in quasar detection. The principal alternative method of identifying these high redshift quasars has been to use a CCD on a 5m telescope. Table II shows the numbers of high redshift quasars detected according to method.

It is clear that the two main methods of finding high redshift quasars are complementary: large area coverage is needed to find the brighter objects and a large telescope is needed to find the fainter ones. However, interpretation of the small-field results could be complicated if the quasar distribution contains structures like the one found by Clowes & Campusano (1991). Clearly, a wide-field programme is necessary to identify these structures.

TABLE II Numbers of quasars with $z \geq 4$

Mag(R)	UKST+APM (colour)	Grism+ CCD+5m	Radio +APM	UKST prism	Seren- -dipity
≤ 18	23	0	0	1	0
19	6	3	1	0	0
≥ 20	1	7	0	0	1
Total	30	10	1	1	1

4.2. The Main Scientific Returns from the Surveys

The following paragraphs identify the types of scientific programme that use the photographic sky surveys - there is insufficient space for a comprehensive review within each category.

i. New objects identified by visual morphology: The visual inspection of sky surveys has been the means of identifying numerous extended objects and systems of objects, including: galaxies, clusters of galaxies, planetary nebulae, 'cometary globules', compact dust clouds and star clusters (see Cannon 1984). Of note is the discovery of the local group, dwarf, spheroidal galaxy in Carina. Previously, the POSS-I Survey had been the source of four new local group galaxies.

ii. New structures and objects found through plate measurement: The recently identified Sextans and Sagittarius local group, dwarf, spheroidal galaxies (Ibata et al., these proceedings) come into this category; so do the galaxy surveys (e.g., Maddox et al. 1990) which take the form of quantitative maps of 2 million galaxies brighter than $B_J \sim 20.5$ constructed from measurements of ~200 SERC J-Survey plates; they allow deep studies of 2D galaxy clustering. Similar work has started on the northern sky from the POSS-II Survey. Also of note are the new LSB galaxies found in the Virgo and Fornax clusters (see Impey 1993). Combined measurements of J-Survey and Objective Prism Survey plates have

allowed the identification of a catalogue of ~1000 quasars of $B_J < 18.7$ in ~200 square degrees (Hewett et al. 1991).

iii. Objects selected by colour: Although most work of this type has come from specially taken sets of plates, surveys have made important contributions. Of note is the use of the R and I Surveys for finding high redshift quasars and very red stars with extremely low mass, possibly brown dwarfs.

iv. Faint extensions to objects: Extensions to known galaxies have been sought through photographic amplification techniques including plate addition. Malin & Hadley (these proceedings) are continuing in this work, often using the multiple plates available on certain fields (see §3.2).

v. Identification of non-optical sources: Sources discovered with X-ray, infrared and other satellites and with radio telescopes need to be observed in the optical. Surveys have proved invaluable for identifying the optical targets.

vi. Object confirmation: Surveys are often consulted to confirm the class of a newly identified object. For example, any object found during the Edinburgh-Cape Survey and suspected of being extended is checked on the SERC-J Survey; planetary nebula candidates found on objective prism plates are checked on the surveys for both colour and variability (see Morgan 1994).

vii. Satellite support: Construction of the HST Guide Star Catalogue depended crucially on measurements of the Sky Surveys (Lasker et al. 1990).

viii. Photographs: Surveys have been a prime source of illustrative material in books and journals.

ix. Positions: Surveys are used for obtaining positions of objects for observing runs; high accuracy is particularly important for positioning optical fibres in multi-object spectroscopic systems.

x. Proper motions: Large numbers of high proper motion objects have been identified in the north by Luyten (1963); the search for high proper motion objects in the southern hemisphere was one of the driving forces behind the AAO-R Survey - see MTSHC.

xi. Variability: Second epoch surveys reveal many kinds of variable, including supernovae (Reid & Djorgovsky 1993).

It is clear from this list that the sky surveys have played many important foundation roles in modern astronomy and, though often making apparently subsidiary contributions, are crucial to the success of many projects.

4.3. The Influence of Surveys on Photographic Research

The nature of the research programmes carried out on the UKST has changed steadily throughout the twenty years of UKST operation. These changes for the years 1973–1990 were described by MTSHC. Addition of the years to 1993 confirms these trends. Broadly speaking, work on stars and quasars has increased throughout the period whereas work on external galaxies has decreased steadily from a peak around 1979. Also, projects needing plates for identifying unknown objects detected at other frequencies (e.g., radio and X-ray) are on the decrease. All this reflects the increasing availability of the sky survey material.

These ideas are substantiated by statistics of the publications based on UKST plates. The ratio of publications based on surveys to those based on special project plates has increased steadily from ~0.7 to ~1.4 over the last seven years.

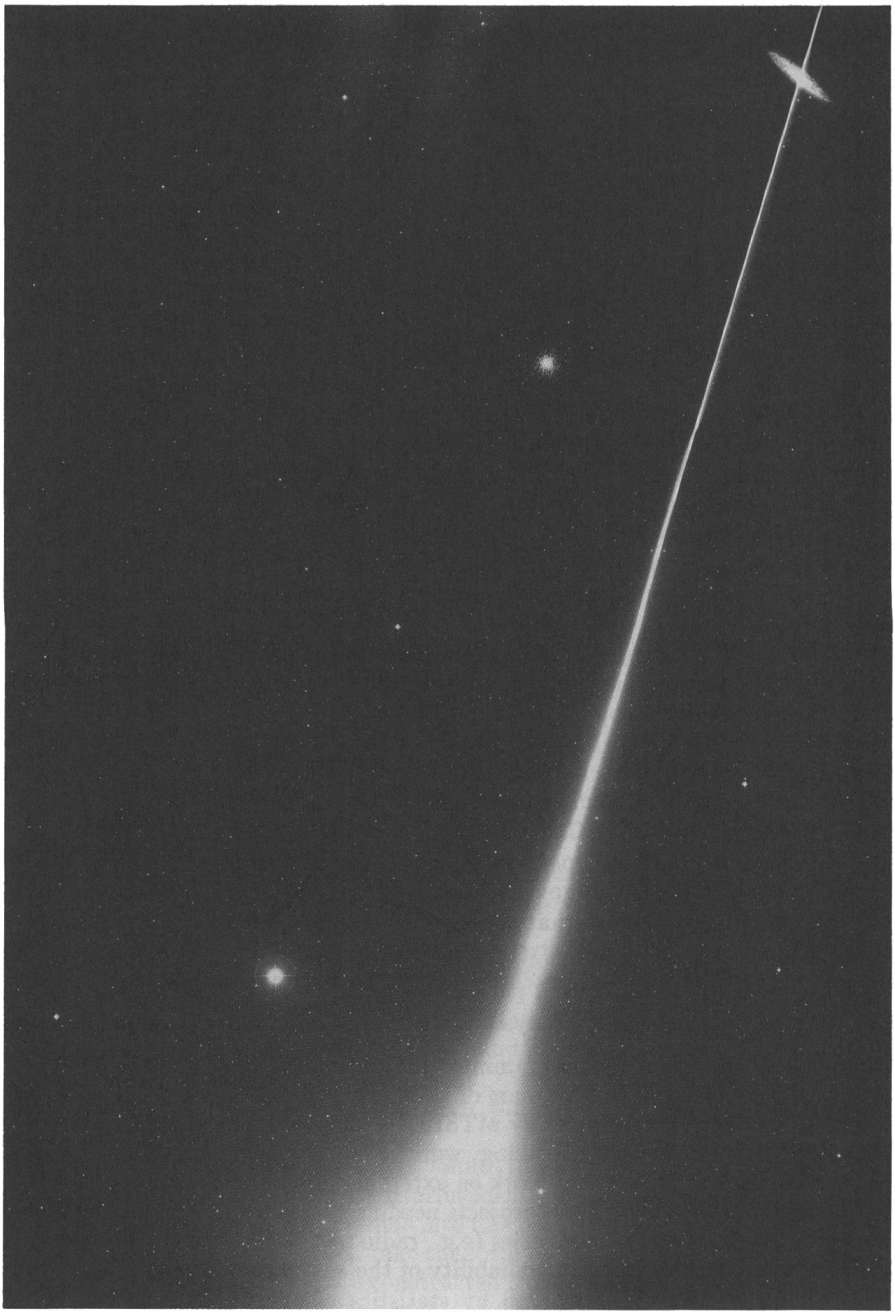

Figure 1. A fireball crossing the South Galactic Cap and spectacularly bisecting the galaxy NGC 253. The plate, which is UKST plate J14546, was taken on September 8th 1991.

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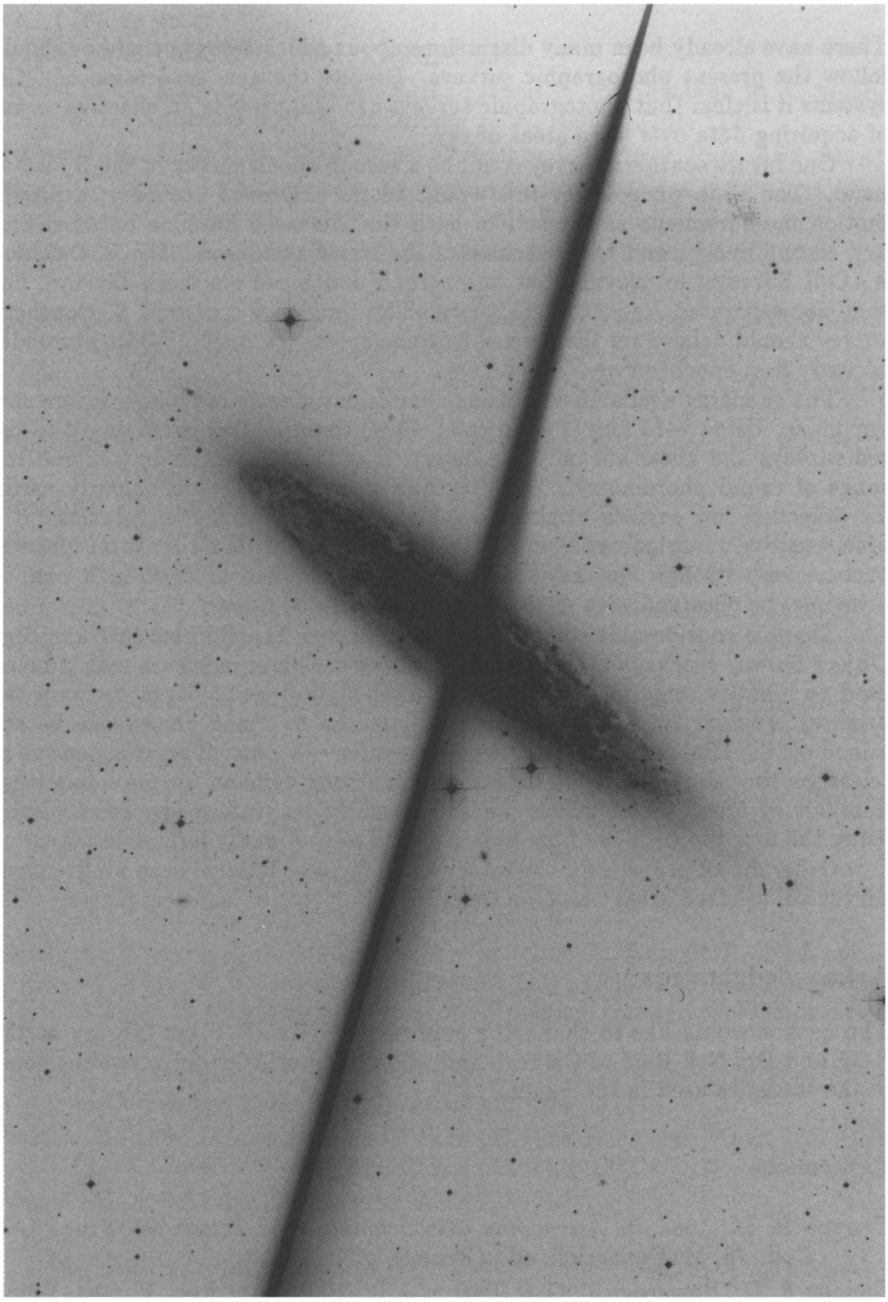

Figure 2. A close-up view of the section of Plate J14546 centred on NGC 253.

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5. Future Surveys

There have already been many discussions about which surveys could or should follow the present photographic surveys. Despite the new generation of CCD systems it is clear that photographic surveys can still provide an effective means of acquiring data over large areas of sky.

One future southern survey could be a second epoch survey in the B_J waveband. The main purpose for this would be the improved accuracy in proper motion measurements as a result of both the increased baseline between first and second epochs and the matching of the wavebands used. The ESO-R and AAO-R Surveys do provide first and second epoch red southern surveys, but they are separated by just 10-15 years. The timing of a second B_J southern survey should depend on the desired astrometry. In the north, POSS-I provides an early first epoch survey.

The changing availability of Kodak emulsions greatly influences future survey plans. Using 4415 film (Parker et al. 1994) could add an extra depth to the red surveys and allow not only the detection of fainter objects but extend the range of useful photometry. The very fine grain would be particularly useful for detecting low surface brightness galaxies and extensions to galaxies. If a blue sensitive emulsion can be made then the case for a blue survey on film will become very strong. On the other hand, any waveband bluer than R can, in principle, be observed with 4415 film using a suitable filter.

There is considerable call for a deep U-Survey. The Edinburgh-Cape Blue Object Survey reaches ~ 18 mag from U plates of 60min exposure and is being used to identify large numbers of interesting blue objects. Even so, only the brightest quasars are being reached. U plates up to 3 mag deeper can be obtained on the IIIa-J emulsion but need exposures ~ 3–4hrs. This is expensive in telescope time, but deep U plates are now in strong demand for providing large numbers of blue objects which can subsequently be studied spectroscopically using the new multi-object fibre systems available on many large telescopes.

Other major projects for the future could include detailed deep multi-colour surveys of selected areas based on the addition of sets of identical plates.

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