PHOTOGRAPHIC SKY SURVEYS

Days of Future Passed

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1. Introduction

Photographic surveys have played a vital role in virtually every area of astronomical research over the last 50 years. Indeed, one can make a strong case that Schmidt telescopes in general, and the Palomar 48-inch Schmidt in particular, have made the most substantial contribution to our understanding of the Universe—at least at optical wavelengths. The all-sky atlases compiled since the initiation of the POSS I O/E survey in 1949 will continue to provide fundamental reference catalogues and potent research tools for many years to come (for our children's children's children), particularly when combined with the second epoch surveys currently under way. However, as far as undertaking new, large-scale sky surveys are concerned, it is clear that we have reached the end of an era. Alternative detector technology and new instrumentation (*i.e.*, CCD mosaics) can now match and, indeed, exceed the capabilities of the photographic Schmidt telescopes in undertaking effective wide-field photometric surveys.

In this review, I report on the progress being made in completing the all-hemisphere photographic surveys currently being undertaken from Siding Spring with the UK Schmidt and from Palomar with the Oschin Schmidt. I also provide a summary of the availability of machine scans and/or object catalogues derived from the various surveys. Photographic survey work is not confined to these atlases, however, and section 3 provides discussion of other more specialised projects currently being undertaken. Finally, I consider the future possibilities for photographic Schmidt surveys.

2. The All-Sky Surveys

Atlas-style photographic surveys covering both the northern and southern celestial hemispheres are underway at the Oschin Schmidt telescope

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on Palomar mountain, California, and the UK Schmidt telescope at Coonabarabran, New South Wales. There have been numerous reviews summarising the properties of the atlases produced from these telescopes, most recently by Morgan (1995), so I only cover recent progress on the incomplete surveys in the present talk.

Both Schmidts are 1.2-metre (48-inch) aperture telescopes and both are currently working on completing surveys using IIIaJ (blue), IIIaF (red) and IVN (near infrared: $\lambda_{eff} \sim 8000\mathring{A}$) emulsions. Each telescope has an unvignetted field of view of $\sim$ 3 degrees radius, a plate scale of $67''.14$ mm^{-1} and is taking plates on a grid of field centres with 5-degree spacing. The seventy-two fields at 0° declination are being covered from both sites, allowing direct comparison of the sensitivity of the two surveys. Overall, the agreement is excellent—the dispersion in limiting magnitude between the northern and southern plate material is comparable with the internal dispersion of either atlas alone. Thus, once suitable calibrated, it will be possible to combine data from these two enterprises to provide the deep, uniform, all-sky catalogues required for investigations such as studies of large-scale structure in galaxy clustering and irregularities in our own Galaxy.

TABLE 1. Sky surveys currently in progress

Survey	Declination range	Emulsion	Filter	Accepted	Total	Comp.
SERC EJ	$0 \geq \delta \geq -15$	IIIaJ	GG395	288	288	100 %
SERC ER	$0 \geq \delta \geq -15$	IIIaF	OG590	257	288	89 %
SERC I	$\delta \leq 0$	IVN	RG715	665	894	74 %
AAO R	$\delta \leq -20$	IIIaF	OG590	508	606	84 %
POSS II J	≥ 0	IIIaJ	GG385	808	894	90 %
POSS II F	≥ 0	IIIaF	RG610	785	894	88 %
POSS II I	≥ 0	IVN	RG9	558	894	62 %
USNO J	≥ 0	IIIaJ	GG385	808	894	90 %

Table 1 summarises the status of plate-taking in the surveys currently approaching completion. In the south the SERC Equatorial J survey has been completed since the Bandung meeting, while significant progress has also been made in obtaining accepted plates for the SERC equatorial and the southern AAO R-band surveys. Finally, the I-band IVN survey is an extension of the original Milky Way survey (spanning 163 fields) to cover the entire southern hemisphere. The completion of both this survey and the POSS II I-band survey were originally threatened by possible difficulties in obtaining plates from Kodak. Fortunately, Kodak has developed a synthetic gelatin and IVN plate availability is no longer a problem. Besides the survey observations, at least 50 % of the time at the UK Schmidt is devoted to smaller scale individual research projects, both photographic and with the FLAIR multi-object spectrograph (Watson 1995).

The Oschin Schmidt is devoted full-time to POSS II, so we have made somewhat greater progress towards the completion of the northern second-epoch sky surveys. (The USNO J survey consists of 3-minute, unhypered II-IaJ exposures designed to provide an intermediate grid of reference stars to tie astrometric measurements of faint objects to the HIPPARCOS/TYCHO catalogues.) However, I should emphasise that the fields remaining in all three passbands are *not* distributed in a uniform manner over the celestial sphere, but are concentrated between right ascensions of 6 hours and 14 hours. This is not a coincidence—it is, in fact, known as winter. An inspection of the plate logs from Palomar shows that while we were able to take 30–40 plates a month between November and March during the early years of the survey, when California was experiencing a severe drought, an average of only 5–10 plates per month is more characteristic of recent years. This concentration is something which other (terrestial) surveys should bear in mind. One can, perhaps, even codify this as Reid's two rules of sky surveys: first, the survey will take at least twice (and usually thrice) as long to complete as your most pessimistic estimate; and, second, that the weather will be best when you are least prepared to take advantage of it, and will deteriorate throughout the course of the survey.

As described in Reid *et al.* (1991), Palomar now lies at the crossroads of several well-used aircraft routes, and, as a result, between 10 and 15 % of the plates taken have aeroplane trails. Aesthetically, these trails are displeasing, but, with a width of ~ 1 arcminute at most, each trail covers a mere 0.03 % of the area of a Schmidt field, and the main aim of POSS II is to provide a scientifically-useful modern survey of the northern sky, not a picture album. Had we but world enough and time, we would aim to replace all of these plates, together with all other plates with small-scale non-uniformities. Unfortunately, we do not have that luxury, while at my back I hear, Sloan Digital Sky Survey hurrying near. Thus, while we will obtain replacement plates for as many as fields as possible, some will remain in the final film atlas issued by the European Southern Observatory (1100 fields issued to date).

Few surveys have the luxury of being able to assume that instrumental parameters remain constant throughout the entire course of observations—and that is certainly not the case for the Oschin Schmidt. Modifications to the system (telescope, plate-holder, guider, *etc.*) have been made throughout the course of the survey, with the most recent being the installation of a motorised polar-axis adjustment at the beginning of the present year. Some of these modifications can influence astronomical analysis. In particular, a vacuum system, similar to that in use at the UK Schmidt, was installed in the plate-holder in April, 1987 and the plate mandrells re-ground to the correct radius of curvature later that year (see Reid *et al.* 1991 for an explanation of why they were originally ground to match the wrong radius of curvature). Since the vacuum system forces the glass plate to conform more closely to the surface of the supporting mandrell, there is a significant difference in the systematic astrometric residuals for plates taken before (*e.g.*, Quick V survey) and after this modification. This obviously has to be borne in mind when computing average global plate solutions.

Most of the available sky surveys have been scanned and processed to produce object catalogues by one or more of the various plate-scanning engines described by Lasker (1995). Table 2 lists those currently available.

TABLE 2.

Machine	POSS I	POSS II	Southern	Availability
APM	O, E		J, R	WWW
APS	O, E			WWW
COSMOS			J	WWW/NRL
DSS	E	J, F, N	J, EJ, R, ER	WWW
PMM	O, E, Wh	UJ, J, F, N	J, EJ, R_{ESO}, ER	CD-ROM
SKYCAT/DPOSS		J, F, N		

APM: Matched O/E image catalogues for POSS I fields above $b = 20°$ are currently available from the RGO/Cambridge WWW site, and a similar high-latitude catalogue is under construction.

COSMOS : The ROE COSMOS scans of the SERC J survey are on-line at AAO, MPI and NRL, with the last set accessible over the world-wide web. Scans of the other southern surveys and POSS II films are planned using the next-generation machine, SUPERCOSMOS.

APS: The Minnesota group has produced a POSS I blue/red matched image catalogue, listing co-ordinates, magnitudes, colours and morphology. A complementary image database (0.33 arcsecond pixels) is currently partially complete, while scans of Luyten's second-epoch (1962–1970) Palomar E-plates will be incorporated in a proper motion database (see Cornuelle, this volume, p. 467).

DSS: STScI is currently adding scans of second-epoch POSS II and southern J, F survey plates to their on-line Digital Sky Survey. Scans of the Palomar Quick V survey are also available.

PMM: Monet and co-workers at Flagstaff have completed scans of not only all the available POSS I, POSS II and southern atlas plates, but also of the short-exposure UJ plates and the Palomar/Whiteoak extension. A preliminary version of the resultant catalogue is available, while a full catalogue (including proper motions to $-48°$) is expected by mid-1997 (Canzian, this volume, p. 422).

SKYCAT: This is a separate analysis of the STScI POSS II scans being undertaken by a Caltech team led by Djorgovski (see Djorgovski, this volume, p. 424).

One point to emphasise is that the utility of these catalogues is crucially dependent on the accuracy of the photometric calibration. Various studies have shown how galaxian large-scale structure analyses can be compromised by inadequate calibration. A bare minimum requirement is one standard sequence extending to the plate limit in each field, and multiple sequences cannot hurt. GSPC-II and the work at Palomar by de Carvalho *et al.* will go some ways towards meeting this requirement, while (in 5 years time) SDSS will also have a substantial impact in the north, but obtaining reliable calibration must stand as the highest priority in large-scale survey work.

3. Specialised Photographic Projects

Besides the encyclopaedic all-sky surveys, various groups have been conducting smaller-scale efforts directed towards more specific aims. While there is insufficient space in these proceedings to cover all such projects, it would be misleading as a question of balance, to ignore them entirely.

UK Schmidt: As mentioned above, at least 50 % of the time on this telescope is devoted to non-survey projects. Multicolour (UB$_J$VRI) plates have been used to search for high redshift QSOs (McMahon), bright QSOs (Hewett *et al.*), low-mass stars (Hawkins, Jones, Thackrah) and blue stellar objects (the Edinburgh-Cape survey), as well as used to map the neighbouring LMC & SMC (Hatzidimitriou). The AAO staff have also been at the forefront in the use of fine-grain Techpan film, which offers significant gains over IIIaF emulsion (see Parker, this volume, p. 179)

Hamburg: The Calar Alto (formerly Hamburg) Schmidt is being used undertake an objective prism survey of the northern sky above $b = 20°$, with the plates (and complementary direct plates) scanned using the Hamburg PDS (Hagen *et al.* 1995). While the main aim is compilation of a QSO catalogue, the survey has also proved invaluable as a source of hot subdwarfs and for identifying ROSAT sources.

Paris: Several intermediate-scale projects are being undertaken with the MAMA scanning machine, based primarily on plates from the ESO

Schmidt. These include the DUO (Bulge) and EROS (LMC) gravitational lensing projects, surveys for long-period variables, Galactic structure analyses as well as studies of large-scale galaxy clustering.

Yale: The Lick Northern Proper Motion survey established a grid of astrometric standards to 18th magnitude in the northern hemisphere (these plates are slated for measurement on the PMM in the near future). This survey is being extended to the southern hemisphere by Yale.

Extensive photographic projects are also being conducted at Kiso, Asiago, ESO and Muenster.

4. New Horizons

The first survey undertaken in a particular wavelength régime requires no ulterior motive—something interesting and new will turn up (even a null result can be interesting). Subsequent surveys, however, demand more specific justification. As a rule of thumb, I suggest that a minimum requirement is an improvement of at least a factor of three (preferably 10) in measuring a scientifically interesting parameter. Marginal improvements generally only give marginal results. POSS II satisfies this criterion by providing an order of magnitude ($\times 10$) more depth at B and I, and a factor of 4 higher accuracy in μ over previous surveys.

Accepting this threshold criterion, what does the future hold for large-scale photographic surveys? Not a great deal. The main advantage offered by Schmidt telescope photography is surveying a large solid angle to relatively faint magnitude limits in a relatively short time. We can define the photometric efficiency of the system as

$$E_p = \Omega \times T_{mag}$$

where T_{mag} is the time taken to reach a given apparent magnitude with a given signal-to-noise—a parameter which depends on telescope aperture, the number and efficiency of optical elements, detector quantum efficiency and overheads such as mounting/dismounting plates and reading out a CCD. If we compare photography on a 1.2-metre Schmidt against CCD observations on a 2.5-metre conventional telescope, there is a factor of four difference in aperture and, at least at R and I, a factor of > 15 in DQE. CCD readout time is negligible if one operates in scanning mode along a great circle (which places stringent, but not excessive requirements on the telescope drive). The unvignetted field of the Schmidt is ~ 29 square degrees, so a $30' \times 30'$ CCD imager can match the Schmidt in photometric efficiency.

Astrometrically, the large-scale rigidity of the glass substrate supporting the emulsion on a plate (plus the fact that one is working at room temperature at all times) gives photography a substantial advantage over CCD mosaics. However, once one all-sky survey is completed, the main purpose of subsequent surveys (astrometrically) is to determine proper motions. The surveys listed in Table 1 provide second-epoch data for the whole sky and, since proper motion is linear with time and we have baselines of 20 and 40+ years in South and North respectively, there appears to be no urgent necessity for a third epoch survey until at least 2045. By that time I would expect photography to have been completed replaced by space missions such as SIM and GAIA, ground-based CCD transit surveys, *etc.*

However, while the justification for a new all-sky photographic survey is at best tenuous, that does not mean that Schmidt photography will not remain a useful tool for smaller-scale projects. The uniformity of photographic emulsions makes them well suited for studying low surface-brightness features (Malin 1994), while the wide field covered on a single exposure remains a distinct advantage in many programmes, such as supernova searches (the POSS II team, mainly J. Mueller, has discovered 57 supernovae in the course of the survey—an order of magnitude more than most dedicated SN surveys), comet and asteroid surveys, A photographic Schmidt is always more efficient if the requirement is a wide-field and a *bright* limiting magnitude. These smaller-scale, scientifically-focused projects, using modern emulsions, should represent the only future application of astronomical photography.

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References

Hagen,H.-J., Groote, D., Engels, D., Reimers, D. (1995), Astron.Astrophys.Suppl., **111**, 195

Lasker, B.M. (1995) "The Future Utilisation of Schmidt Telescopes," Astron.Soc.Pacific Conference Series, 84, p. 177 (ed. J. Chapman, R. Cannon, S. Harrison & B. Hidayat)

Malin, D. (1994) IAU Symposium 161, "Astronomy from Wide Field Imaging," p. 567 (ed. H.T. MacGillivray *et al.*: Kluwer Academic Publishers, Dordrect)
Morgan, D.H. (1995) "The Future Utilisation of Schmidt Telescopes," Astron.Soc.Pacific Conference Series, 84, p. 137 (ed. J. Chapman, R. Cannon, S. Harrison & B. Hidayat)
Reid, I.N. *et al.* (1991) Publ.Astron.Soc.Pacific, 103, 661
Watson, F.G. (1995) "The Future Utilisation of Schmidt Telescopes," Astron.Soc.Pacific Conference Series, 84, p. 71 (ed. J. Chapman, R. Cannon, S. Harrison & B. Hidayat)