THE ESO SKY SURVEYS

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ABSTRACT

Technical aspects of the production of photographic Sky Surveys and Atlasses are discussed. The need to optimize all factors, e.g. telescope site, telescope optics, mechanics and control system, hypersensitization, calibration, processing and reproduction is illustrated by the ESO 1m Schmidt telescope and the ESO Sky Surveys.

1. INTRODUCTION

Many photographic sky surveys have been undertaken during the past 100 years. Each of these constitutes a "snapshot" of a part of the sky, and thus provides 1) a record for later research, 2) an inventory of objects in that sky area and 3) identification of objects already known. The general expression is $I = \overline{I\ (\alpha, \delta, \lambda\ ,\ t)}$ which emphasizes the significance of the time parameter: Any sky survey provides a basis for comparison with earlier and future observations and therefore the possibility of discovering and studying variable phenomena. The best known modern photographic sky surveys are those undertaken at Palomar, at the European Southern Observatory and with the UK Schmidt telescope. References are, for instance, found in the papers by by Minkowski and Abell (1963), West (1972) and West and Schuster (1982).

My talk today has been preceded by Professor Woltjer's introduction, dealing with many astronomical aspects of the work with wide-angle telescopes, including the types of discoveries which are possible with such instruments. The next speaker, Dr. R.D. Cannon, will tell you about the highlights of research with the UK 48" Schmidt telescope. I therefore feel that I should not try to repeat these two speakers by going into detail about the rich discoveries made by the ESO 1m Schmidt Telescope and by attempting to summarize the many current astronomical research projects based on the ESO Southern Sky Surveys. It came to my mind that whereas we often talk about scientific research, we seldom realize and discuss the great technical difficulties in obtaining the

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high-quality photographic plates which are the basis for modern sky surveys. Thus, I have decided to concentrate mostly on the various phases of making such plates, starting with the telescope site and following through until the atlas copies have been distributed. Only thereafter can astronomers all over the world benefit from a survey and start making real astronomical use of it.

In describing the various problems which have been encountered with the ESO Schmidt and at the ESO Sky Atlas Laboratory over the years, I hope to impress upon those who decide to undertake similar projects and those who are just regular users of wide-angle telescopes, how important it is that every link in the chain is optimized. Whenever something goes wrong, the end product will suffer and will not contain the astronomical information which we expect it to carry. Talking with colleagues from other Schmidt telescopes, it has become abundantly clear to me that they have very similar problems, although this is perhaps not always told to the public in a loud voice. I shall therefore in this paper try to expose some of the major problems which were encountered during the production of the ESO Sky Surveys and, fortunately, in almost all cases solved in a satisfactory way.

2. ELEMENTS OF A SKY SURVEY

Chronologically, the elements which are necessary for the achievement of a successful and useful sky survey are the following: telescope site (altitude, climate, seeing); telescope (optical, mechanical and control systems); photographic material (availability, spectral sensitivity, speed, etc.); hypersensitization (methods, stability); exposure at telescope, calibration, processing, copying of original plates, protection and archiving of originals and copies and finally, distribution of the resulting atlasses. In what follows, we shall take a closer look at some of these points in connection with the ESO 1 m Schmidt telescope and the ESO(B) and ESO(R) Surveys.

2.1 Site and Telescope

The ESO La Silla site is probably one of the best on earth. In addition to a large number of clear nights (at least 2500 hours per year) it has a significant fraction of very good seeing of obvious benefit to any seeing limited observations, e.g. the taking of survey plates with the ESO 1 m Schmidt.

The ESO Convention of 5 October 1962 specifically mentions a Schmidt telescope of about 1.2 m aperture, but in the end a 1 m telescope was built as an improved copy of the Hamburg Schmidt telescope. The mirror is 162 cm, the focal length is 3065 mm (plate scale 67.45 arcsec/mm;

the field is 290 x 290 mm^2, or 5°5 x 5°5. The constructor was W. Strewinsky (who also built the Hamburg Schmidt) and the telescope entered into operation in 1972. It soon became clear that, although the ESO Schmidt was improved in several respects as compared to the Hamburg Schmidt, it was not able to take full advantage of the very good seeing at La Silla, the desire to make long exposures in the dark La Silla sky, and the recent availability of high resolution emulsions. These three factors together put very high demands on the optical and mechanical characteristics of the telescope, expressed through the need to achieve near perfect guiding over several hours.

Much of the time during the past 10 years has been spent in significantly improving the performance of the ESO Schmidt telescope in order to make it possible to obtain deep survey plates of near perfect quality, i.e. with good surface uniformity, little or no image distortion, the smallest possible stellar images and thereby deep limiting magnitudes. Dr. André Muller of ESO has made a great personal contribution to this aim, and I am very thankful to him for information about the various improvements. Further details can be found in various papers; Muller (1979a, 1979b, 1980, 1983).

The ESO 1 m Schmidt telescope is basically extremely sturdy, and the optics is of reasonably good quality. Nevertheless, it was necessary to change and/or improve many features, the most important of which will be mentioned here:

Azimuth and Polar Setting

The telescope cradle is placed on four legs. Although this is a very stable system, it complicates azimuth and polar setting. The problem was overcome by introducing hydraulic jacks with spherical base and top, which take up the weight of the telescope during corrections, and which function like ball bearings allowing smooth corrections to within 1 arcsec. Azimuth and elevation are read from dial gauges and changes can be made through the night, especially after the installation of remotely controlled elevation setting.

Right Ascension Gear

An instability was present whenever the telescope passed the meridian. This was overcome by applying a small preload to the polar axis with a momentum of 32 kgm.

Oil System

The south end of the polar axis is supported by oil pads. Initially, the oil was heated during the night and the pads stuck due to change in viscosity. An oil cooling system was installed and the problem disappeared.

Declination Gear Wheel

In the original design of the declination gearing, springs were included to absorb earthquake shocks. However, this made the telescope very sensitive to wind, and oscillations frequently occurred. Therefore, a classical long arm declination control was installed allowing for declination corrections up to ± 1 arcmin. The telescope is now completely stable up to wind velocities through the slit of 10 metres per second.

Control System

The entire telescope control system for pointing and tracking was replaced by an ESO produced TCS system, similar to that used for the ESO 3.6 m telescope. This system is based on a Hewlett Packard 21MX computer. Pointing is possible with an accuracy of ± 3 arcsec and offset tracking with variable tracking rates etc. is also included.

Mirror Cell

Although the mirror cell is basically well designed, it was found that the positioning force was not succifient, causing collimation errors, especially when the telescope was placed in loading (horizontal) position. This was overcome by the installation of telescopic springs aligned with the center lines of the invar rods. They push the mirror with a constant force against the ends of the invar rods.

Plateholder

Of all problems, those connected to the plateholder in the center of the main tube were the most difficult. The longest possible exposure on medium grain emulsion (e.g. IIa-O) without serious image elongation was one hour, which was just sufficient for the production of the ESO (B) Atlas. However, longer exposures could not be satisfactorily achieved, and the main reason was finally located in the spring connection of the plateholder unit with the tube wall. This spring compensated for the weight of the plate carrier when it was lowered inside the tube to receive the plateholder. Consequently, a completely new plateholder unit was designed. It has no direct mechanical connection with the tube wall and is only supported by the focussing cylinder at the center of the spider. The plateholder is now placed directly by the observer in

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the center of the tube. To reach this area, he is lifted by a moving platform up through the loading hatch while the telescope is in loading position. The solution effectively eliminates the above mentioned problem and satisfactory exposures are now possible for up to 6 hours.

Guiding

While improving the plateholder stability, it became obvious that the mechanical connections of the two guiding tubes to the main telescope tube were not sufficiently stable. In order to benefit from the improved plateholder design, it became necessary to install a TV guiding system in the main tube, just off the plateholder. It is mounted on the plateholder unit to assure absolute stiffness between the photographic plate and the crosswire of the offset guider. As it is mounted inside the camera tube, it uses about 70% of the aperture and thus has an effective diameter of 84 cm. The guide probe and cross-wire are projected on a TV camera with an EBS tube and a window diameter of

40 mm. Guiding is done in the control room by remote control. In addition, the guider has a prism device which can be shifted into the field whenever objective prism plates are obtained, making it possible to reduce the spectra to star points and hence retain the guiding accuracy. Guiding down to magnitude 13 is now possible.

Electronic Cross

Since the guiding is no longer done at the center of the plate field, but approx. 3 degrees away, it is necessary to overcome the effect of differential refraction during longer exposures. An "electronic cross" device has therefore been installed which produces two crosses on the TV guide monitor. One cross is fixed and its position is calibrated with the optical cross of the guider which is also imaged on the monitor; these crosses are then solidly linked. A second cross is produced by computer software and can be moved with respect to the fixed cross. The correction includes the differential refraction effect and can also take into account offset guiding on moving objects. The device has proved extremely useful for recovering very faint comets by blind offset guiding. No fewer than six early recoveries were made during the recent years.

Dome Seeing

The Schmidt dome is well isolated and in view of the very small day-to-night temperature fluctuations on La Silla, good seeing is available at the very beginning of the observations every evening. However, it has been felt that there is still room for improvement, and it has been decided to further reduce dome introduced seeing by cooling the observing floor. The installation has not yet been terminated. Moreover, the control room with the observer has been moved from the dome to below.

Achromatic Corrector Plate

The original corrector plate of UBK7 glass was ordered with optimal correction at 4300 A. However, it turned out that a "redshift" had occurred and the best wavelength was 5000 A implying a loss of quality especially in the UV region. An achromatic corrector was manufactured by Grubb Parsons and installed in the summer of 1983. It is currently being tested.

Calibrators

In order to improve the usefulness of survey and other plates for photometric measurements, calibrators were designed (Muller, 1977) and installed in the telescope tube. Each projected 14 steps covering a total interval of $\Delta \log I = 1.4$. However, due to the necessity of blocking light from the sky in the area of the projected wedges, thereby unavoidably introducing a rather large area of vignetting, the calibrators were recently moved from the telescope to a table on the observing floor, and calibration is now made immediately following the telescope exposure.

Other Devices

A multi-diaphragm device has been constructed which allows the exposure on one plate of 36 different sky fields without overlapping. This is particularly useful for a supernova search, which is now carrried out by A. Muller and H.-E. Schuster and which has sofar resulted in the discovery of several supernovae. A Racine wedge is available for photometric calibration. A 4° objective prism gives dispersion 450 A/mm at 4340 A. A complete set of optical filters including interference filters to isolate astrophysically important emission lines is available.

3. PHOTOGRAPHIC MATERIALS AND THE HANDLING OF THESE

The times have passed when the astronomer just took a plate from the box and put it into the telescope to make the exposure. Nowadays, hypersensitization is necessary to take full advantage of the greatly increased capability of modern fine grain, high contrast astronomical emulsions. Various methods are available; cf. e.g. the review by Millikan and Sim (1978) and articles in the AAS Photobulletin.

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At ESO, sensitization by baking in nitrogen has been used for many years, and the standard procedure is now nitrogen followed by forming gas. The entire procedure takes several hours and is the first, difficult step necessary to achieve satisfactory exposures. At various times, severe problems have been encountered, in particular in terms of large scale non-uniformity, which has made otherwise excellent plates useless for the sky surveys. Long series of tests have been necessary to arrive, in an empirical way, at the currently reasonably satisfactory procedures ensuring a uniform sensitization of the 30x30 cm plates. The problems were mainly connected to the gas flow pattern and small temperature gradients inside the hypersensitization box. Tests with hydrogen sensitization are underway, and it is likely that sensitization in pure hydrogen will be incorporated some time in the future. However, the need to ensure absolute safety has so far held back this project. It is believed that a maximum gain in speed of perhaps 30% over the current procedure is possible, e.g. for the IIIa-F plates for the ESO (R) Survey.

After exposure of edge marks, the plate is washed in Freon and exposed in the telescope. The distance between the optical filter and the emulsion is at least 6 mm allowing to avoid area desensitization, during exposure, a problem which has occurred in other telescopes, e.g. at the UK 48" Schmidt telescope. After exposure and calibration, the plates are processed to archival quality, following the latest ANSI and ISO guidelines. Accelerated aging tests have shown that the adopted method will, hopefully, assure plate survival for several hundred years if stored under controlled, optimal conditions. It includes the use of a large Palomar-type tray rocker (to ensure uniformity), a prolonged, agitated immersion in a stop bath, two agitated fixing baths, washing twice, Photo-Flo rinsing, swapping with cotton and vertical drying. The layout of the Schmidt dark room is a result of experience gained at other observatories and, in particular, at the ESO Sky Atlas Laboratory and encompasses several features which contribute to the safe handling of large astronomical plates in complete darkness (cf. West and Dumoulin 1974). Dust contamination is efficiently reduced by a high standard air conditioning system with adequate filters.

The entire process, from removing fresh plates from cold storage until they are put into the drying cabinet may last up to 10 hours, e.g. in the case of the plates for the ESO (R) Survey. This puts considerable strain upon the personnel. Without detailed and efficient preparations, it is not possible to maintain at an optimal level such a procedure. At the same time, it becomes quite clear that even minor technical problems may easily ruin a night's observations or at least incur significant loss of observing time and astronomical information.

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4. PRODUCTION OF ATLASSES BASED ON SKY SURVEYS

Since the mid-1950's, several hundred copies of the Palomar Observatory National Geographical Society Sky Survey (POSS) have been distributed in the form of atlas prints on-paper and on-glass. In order to retain as much information as possible during the copying process, special reproduction methods were employed at the Graphic Arts Facilities of the California Institute of Technology, Pasadena (cf. Minkowski and Abell, 1963). However, since the POSS emulsions (103a-O and 103a-E) are rather coarse, it was not possible to use the same copying methods for the ESO (B) and ESO/SRC Surveys. Thus, when the ESO Sky Atlas Laboratory was set up in Geneva in 1972, a thorough investigation was made in order to optimize the reproduction techniques by making use of the most modern methods and materials. Many innovations are described in a report by by West and Dumoulin (1974), and further details may be found in the papers by West (1978) and West and Dumoulin (1980). In particular, it was decided to use film, rather than paper to allow quantitative measurement on copies, e.g. in transmission.

By making use of fine grain, high contrast materials and bringing down the contrast to approx. $\gamma = 1$, it has been possible to obtain a virtual grain to grain reproduction of the original plates. Major problem areas are now to assure complete physical contact between the originals and the copy plates during exposure without damaging the originals. Extensive use is made of drying copy plates in nitrogen and of Freon cleaning to avoid impurities, lipids, etc. Superior uniformity is assured by appropriate copying devices and processing techniques. Nevertheless, there is a decisive difference between a one time copying of a plate and the "industrial", large-scale production which is necessary in case of the ESO (B) and ESO/SRC Atlasses. The full attention which can be given to individual plates must be replaced by elaborate control methods. Extensive checks of Atlas prints at the ESO Sky Atlas Laboratory effectively assure that most faulty copies do not reach the buyers of the Atlas.

Special attention has also been given to the proper protection of Atlas copies by the use of Tyvek envelopes (glass copies) and two-layer transparent plastic envelopes (film copies). Special packing material has greatly reduced the risk of damage during transport to the subscribing institutes. An overview of the distribution of atlas copies throughout the world will be found in Figure 1; the total nos. are: ESO(B)-film, 42 copies; ESO(B)-glass, 20 copies; ESO/SRC-film, 178 copies; ESO/SRC-glass, 10 copies.

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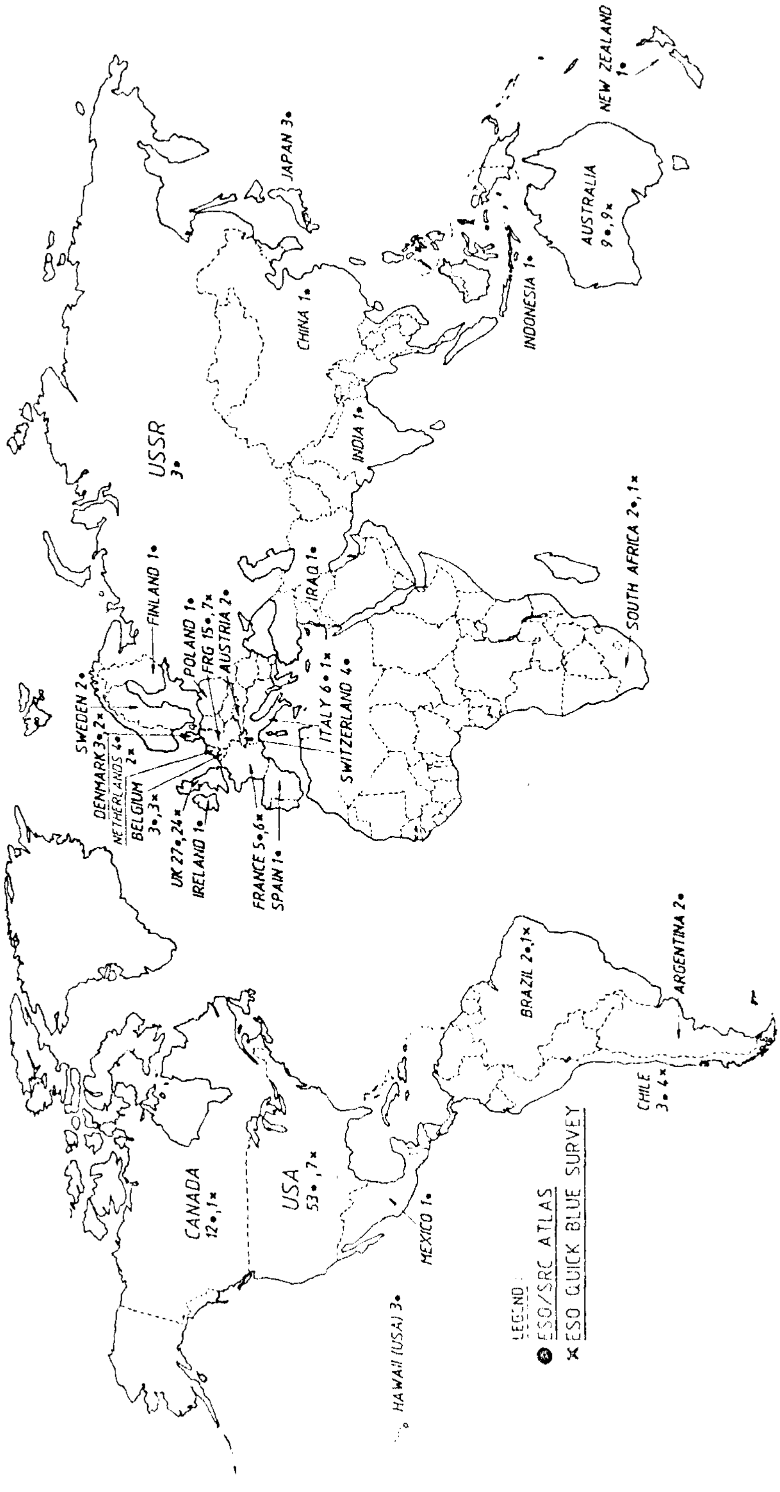
USSR 3•
JAPAN 3•
NEW ZEALAND 1•
AUSTRALIA 9•, 9×
INDONESIA 1•
CHINA 1•
INDIA 1•
SOUTH AFRICA 2•, 1×
FINLAND 1•
POLAND 1•
FRG 15•, 7×
AUSTRIA 2•
IRAQ 1•
ITALY 6• 1×
SWITZERLAND 4•
SWEDEN 2•
DENMARK 3•, 2×
NETHERLANDS 4• 2×
BELGIUM 3•, 3×
UK 27•, 24×
IRELAND 1•
FRANCE 5•, 6×
SPAIN 1•
ARGENTINA 2•
BRAZIL 2•, 1×
CHILE 3• 4×
CANADA 12•, 1×
USA 53•, 7×
MEXICO 1•
HAWAII (USA) 3•
LEGEND:
• ESO/SRC ATLAS
× ESO QUICK BLUE SURVEY

Figure 1

5. ASTRONOMICAL USE OF THE ESO (B) AND ESO/SRC SKY SURVEYS

The utility of the ESO and ESO/SRC Atlasses has been greatly enhanced by the availability of film copies of the survey plates. With the advent of fast measuring machines, many observatories are now able to perform quantitative measurements on their Atlas copies. A photometric transformation is necessarily introduced by the copying process. It has been found that in order to achieve the best possible calibration, it is preferable not to base the calibration curve on the imprinted step wedges only, but also, whenever possible, on calibrated stars and galaxies in the field. Two-dimensional digital devices like the CCD's now permit accurate calibration of objects and therefore the determination of zero points and calibration curves of entire survey plates. However, the danger of large-scale plate non-uniformities should not be underestimated and calibration by "local" objects, say within one degree is definitely recommended.

An example of the use of the ESO (B) Survey is the comprehensive inventory of objects in the southern sky known as the ESO/Uppsala Survey which was compiled by Lauberts (1982). It comprises more than 18.000 objects. Photometric measurement of most of these on the original ESO(R) plates is in progress (Lauberts, private communication) and secondary standards will therefore soon become available in virtually all survey fields.

Inspection of the ESO (R) half of the joint ESO/SRC Survey has already yielded a large number of red objects, many of which are hitherto unknown. Among these are Hα emission objects, red stars and distant clusters of galaxies. A future comparison of the SRC (J) and the ESO (R) plates will undoubtedly provide extensive finding lists of intrinsically red and/or reddened objects.

6. CONCLUSION

I have discussed some of the major technical problems connected with the production of high quality photographic atlasses, e.g. the ESO (B) and ESO/SRC Sky Surveys. It is, of course, not possible to exhaustively describe technical details in this short paper, but by calling attention to some of the most critical problem areas, it is my hope that current and future users of Schmidt-type and other wide-angle telescopes will realize that there is still much room for improvement. These telescopes are extremely powerful tools for many types of astronomical investigations, but in order to derive full benefits from the unique properties of the photographic emulsion as an unsurpassed panoramic detector, continued attention must be given to all those parameters which so easily deteriorate the performance.

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DISCUSSION

J.A. Dawe: Why do you not put on your calibration at the same time as the plate is exposed in the telescope? And a possible relevant rider - What is the average humidity at La Silla?

R.M. West: To avoid the extensive vignetting that is introduced by the calibrators (sensitometers) in the telescope. With 5 degree centers for the survey, this would lead to parts of the sky not being covered by the Atlas. The average humidity is about 30%, thus, there may be less loss of sensitivity at La Silla than what is experienced in some humid places.

V.M. Blanco: I am delighted that you emphasized the high demand now being made on the mechanical stability of Schmidt telescopes. Martin McCarthy and I planned to talk next Friday about the same subject but, unfortunately, we will not be here. However, you have given our speech for us, and we thank you very much. I would like to add a comment to what you said. Namely, present-day large Schmidt telescopes were designed mostly prior or simultaneously with the development of low reciprocity failure emulsions and very large narrow bandpass interference filters. With these developments, observers now often need to make exposures as long as 3.4 or even 6 hours. Unfortunately, the telescopes were only too frequently designed for exposures of two hours or less. Users of the Curtis Schmidt at CTIO know this problem only too well. We have had to spend a tremendous effort in rebuilding parts of the Curtis telescope with some success, I am glad to say, but it has not been an easy task at all.