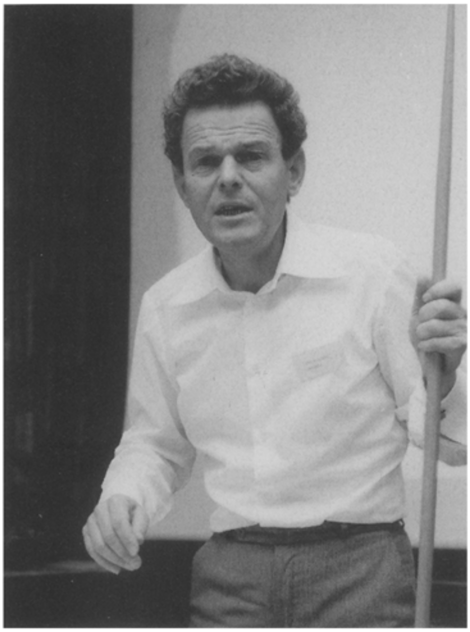
Part VII

Methods and Tools



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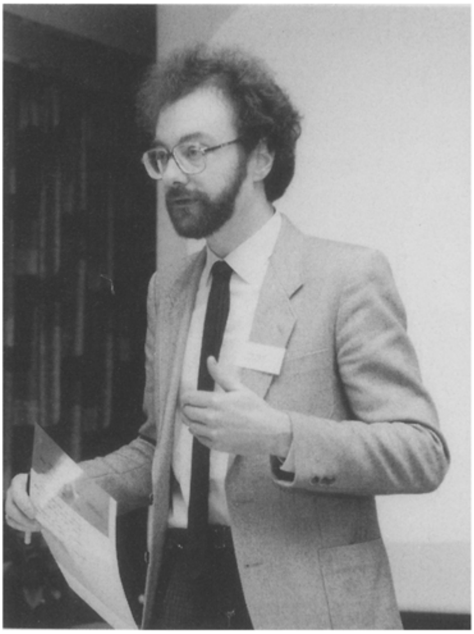

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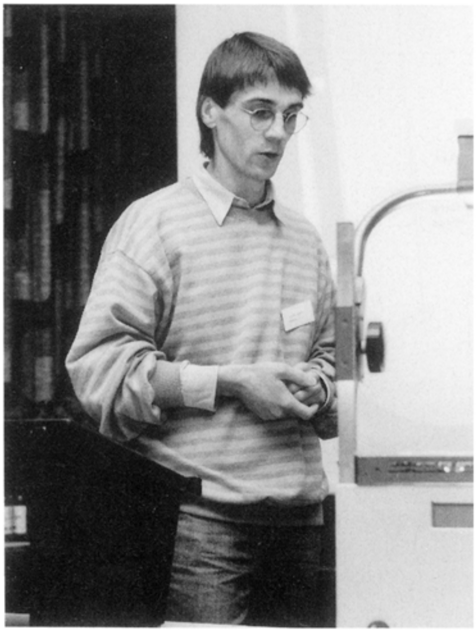

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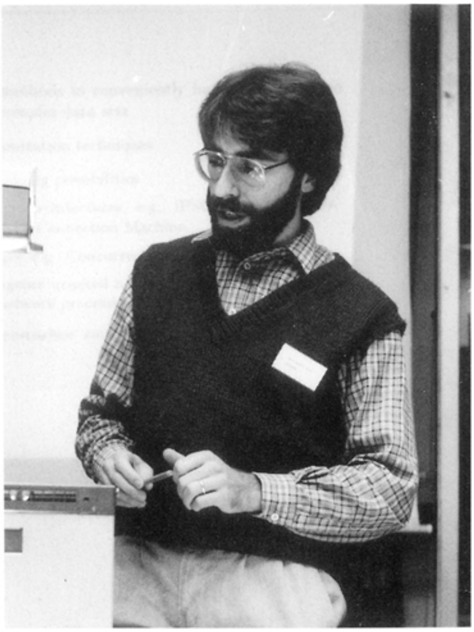

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Photometry from Schmidt Plates

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Abstract

With the advent of fast measuring machines such as COSMOS, there has been a revival of interest in photometry of wide field Schmidt plates. The very large datasets which have now become available are typically used for two types of programme, large scale statistical surveys of the distribution of various astronomical populations, and searches for very rare objects. In each case, good photometry is essential, and a number of techniques have been developed to attain acceptable accuracy over the large fields covered. A number of different approaches are used for detecting objects or defining samples, including magnitude, colour index and variability, in addition to non-photometric methods such as proper motions and objective prism spectra. Each detection method presents its own particular problems, and a number of calibration algorithms have been developed to optimise photometric accuracy.

1 Historical background

Before the advent of the photoelectric photometer, the only method of quantitative photometry was the measurement of photographic plates. Despite the inherent non-linearity of the photographic process, sophisticated algorithms and techniques were developed which, at least in a relative sense, produced stellar magnitudes with quite small formal errors. The introduction of photoelectric detectors enabled the identification and removal of a number of systematic effects, and enabled the production of well calibrated data for large numbers of stars. It was accepted at this time that a large plate scale and several plates in each colour were essential for obtaining accurate and reliable results. Schmidt plates were rarely used for photometry due to their small plate scale, and a number of other problems which will be discussed below.

In the early 1970s fast measuring machines specifically designed to measure Schmidt plates were developed at the Royal Observatory, Edinburgh, and Cambridge University. These machines were designed to detect images above a pre-computed threshold related to the sky background, and output a number of parameters for each image, including position, integrated density, image size, and measures describing the shape of the image.

Early work with COSMOS measures of Schmidt plates was hampered by the small number of plates available at that time. It was rare for there to be more than one plate in any one field which meant that establishing the magnitude and nature of photometric errors, especially as a function of position in the field, was not easy. As a result, much of the early published photometric work was based on only one set of measures of one plate. This break with traditional practice in photographic photometry made for some lack of credibility in early results from the Schmidt/COSMOS combination.

There are however other more fundamental difficulties associated with photometry from Schmidt plates. The small plate scale and hence image size significantly reduces the accuracy obtainable, especially for faint objects. This is clearly a fundamental limitation which can be offset by using a small ($\sim 8\mu$m) measurement aperture although this in itself produces problems associated with the satisfactory definition of the aperture on some measuring machines.

2 Photometric problems

There are a number of problems associated with change of photometric performances across the field of a Schmidt telescope. Perhaps the best known, and least serious, is *geometrical vignetting* caused by obstruction of the light beam to the outer parts of the field by the structure of the telescope. The attenuation of the beam can quite easily be calculated as a function of position of the plate, and appropriate corrections made to the photometry. In fact the corrections are insignificant over most of the field, and only important in the corners. A more serious field effect is caused by *differential desensitization* of the plate while it is in the plate holder. The plate is kept in a curved shape during the exposure to follow the focal plane of the telescope. The filter however is planar, and so traps a layer of damp air of varying thickness over the plate. The damp has the effect of desensitizing the plate, and since the air gap is thickest towards the edge of the plate holder, the effect is proportionally worse towards the edge of the field. This rather serious effect is present on all UK Schmidt plates until about 1981, when the problem was solved by flushing the plate holder with dry nitrogen during the exposure.

Field effects due to intrinsic changes in sensitivity of the emulsion across the plate are generally quite small, of the order of $1-2\,\%$, which for most purposes is negligible compared with other photometric errors. A more serious problem is associated with *changes of image structure* across the field after a long exposure, due to field rotation. Also, any *local defocussing* or *astigmatism* would have a similar effect. With a strictly linear detector, change in image structure would not present serious difficulties, as the total amount of incident flux is not changed, but for a non-linear detector such as a photographic plate, combined with the *thresholding procedure* of COSMOS, the effect on the measured magnitude can be large (> 0.1 mag). There is no satisfactory cure for this problem, apart from ensuring that where possible plates are taken close to the meridian, and that the telescope alignment is carefully monitored to obtain optimum image shape.

3 Modern photographic photometry

The COSMOS measuring machine has revolutionised photographic photometry in a number of ways, but especially in making possible the measurement of large (35 ×

35 cm) Schmidt plates in a reasonable length of time (about 4 hours). The scanning system comprises a flying spot cathode ray tube with a photomultiplier detector. The machine measures plates in lanes 128 pixels across, with a range in pixel size from 8 to 32 μm. The sky background is measured in grid form in a pre-scan, and used to define the threshold above which images are to be detected. This is typically 7 – 10 % above the local night sky level. The images detected above the threshold are analysed and a number of parameters output to tape, including position, image area, maximum intensity, integrated density and several shape parameters defining ellipticity, and major and minor axes. The positional accuracy of the measures depends to some extent on the size of the image, but is about 2 μm.

The integrated density parameter (COSMAG) should in principle be proportional to incident flux. In practice, brighter images are saturated or nearly saturated at the centre, while for the fainter images, the thresholding procedure leads to a systematic reduction in proportion to the flux recorded. There is thus only a relatively small regime where COSMAG provides a strictly monotonic measure of star magnitudes, which is suitable for empirical calibration using a photoelectric or CCD sequence. The photometric accuracy of the calibrated measures depends on the quality of the plate (seeing, background uniformity *etc.*) and also on the size of the image. In favourable circumstances (well exposed images on a good plate) the accuracy is about $\pm 0\overset{\text{m}}{.}06$ increasing to about $\pm 0\overset{\text{m}}{.}10$ near the detection limit ($B = 21$ for a IIIa-J survey plate).

4 Diagnostics and cures

Each COSMOS measure is accompanied by a comprehensive set of diagnostics showing changes in the relation of the various image parameters across the plate. These may be used to check for field effects.

If significant field effects are found to be present, several remedies are available. If only local changes in magnitude are important, such as for variability studies, then the plate to plate transformations may be made as a function of position. If colour effects only are important, then a requirement to keep the main sequence in the same position across the plate will suffice (although in some cases this may not be an acceptable assumption). If it is necessary to maintain the magnitude zero point over the whole field then a grid of photoelectric standards is necessary, although in most cases there is a strong correlation between bright and faint stars, and so bright standards will suffice.

5 Conclusion

As the measurement accuracy and consistency of fast measuring machines improve, new reduction techniques are developed and large numbers of Schmidt plates become available, it is now possible to attain the accuracy of photographic photometry in its heyday, but with an increase in speed of several orders of magnitude.