ANALYSIS OF IMAGES WITH THE APM SYSTEM AT CAMBRIDGE

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The Automated Photographic Measuring (APM) system at Cambridge was started many years ago to analyse Schmidt plates, and its progress has been reported at a number of these conferences. Only brief details of its design will be given in this paper.

The system consists of a very accurate laser-beam scanning microdensitometer connected to a series of on-line computers. The microdensitometer (Figure 1) uses a 5500 kg x-y table to position the plate. The plate transmission is digitised to 12-bit accuracy at a rate of one sample every 4 microseconds, although the image processing hardware limits this speed in practice. Special-purpose hardware exists to convert the transmission measurements into density or intensity estimates, to smooth the spot-size digitally, to measure the background and to compute image parameters.

Previous papers have stressed the importance of accurate background measurements for this work (Kibblewhite et al. 1975, Kibblewhite et al. 1983). In the APM system the plate is scanned twice, once to measure the background using median estimators within 64 x 64 pixel areas (0.25 sq. mm), and then again to measure the images on the photograph. Special-purpose hardware interpolates between the smoothed background measurements so that a background estimate is derived for each pixel.

The machine now works in one of five modes, each of which is fully operational: (1) Background Mode as described above. (2) Image Analysis Mode in which the positions, shapes and sizes of images are measured. A plate can be measured overnight in this mode and software is available on the STARLINK VAX computer for star/galaxy separation and for the collation of data from a set of plates for automated detection of supernovae, variable stars or colour-excess objects. (3) Objective Prism Mode which produces an uncalibrated intensity versus wavelength data-set from each spectrum using a direct plate of the field to define the position of each image. These spectra are calibrated on the VAX and automated classification algorithms can pick up emission-line and other unusual objects (Hewitt, this conference). (4) Raster

M. Capaccioli (ed.), Astronomy with Schmidt-Type Telescopes, 89–97.

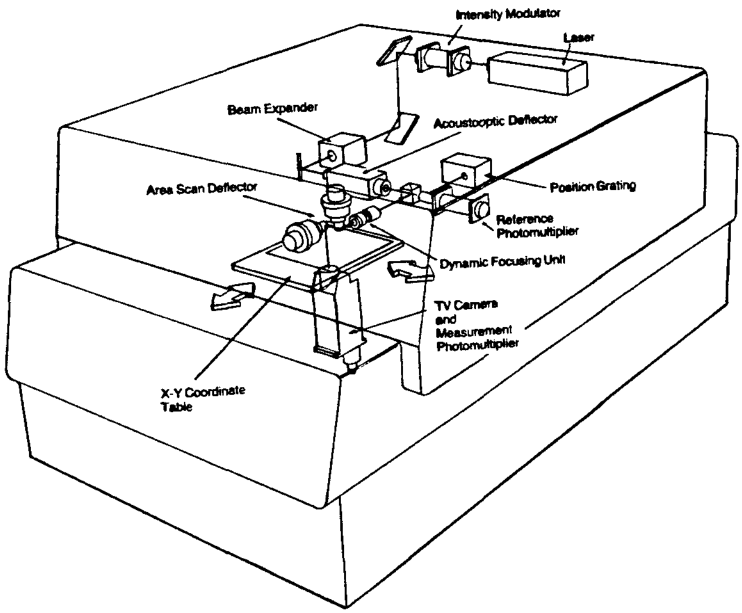

Figure 1. Schematic diagram of the APM microdensitometer.

Mode which digitises given areas of a plate at a speed determined by the magnetic tape-drive (50,000 samples per second). Software for a wide range of tasks is available. (5) Raster-90 Mode in which 90 x 90 raster-frames of hundreds of regions can be scanned automatically. Positions of the scans can be given in right ascension and declination and are usually obtained from selecting interesting images from scans made in either Image Analysis or Objective Prism modes.

The APM system is operated in a similar manner to most large telescopes. Astronomers come to the unit, learn how to use it, and can leave Cambridge knowing they have good data. The microdensitometer is controlled by a comprehensive software package which gives the astronomer great flexibility without the need for detailed knowledge of the workings of the machine. All plates can be aligned using standard reference-star catalogues stored on-line so that all measured image positions are given in right ascension and declination enabling data from a number of plates of the same area of sky to be efficiently collated on the STARLINK VAX. An interactive colour-display allows the user to have a 'quick look' at the data either to experiment with different scanning parameters to suit his objectives or to be certain that he has good data before leaving the facility.

The remainder of the paper will describe four projects currently under investigation which give an indication of the capabilities of the system. Intensity calibration is discussed by Pete Bunclark at this conference and objective prism capabilities are covered by Paul Hewitt.

Detection of low surface-brightness features

The background-scan of the plate contains important data for a variety of astronomical projects and complements the photographic techniques of Malin. In the Background Mode we scan the plate with an 8 micron spot and determine the median (or Maximum Likelihood) density level of the sky background within 64 x 64 pixel areas. The typical photographic noise per pixel is 0.05 density units so we are able in principle to estimate the density in these regions to 0.001 D. However, in practice quantisation errors increase this to about 0.002 D which for IIIaJ emulsion corresponds to a noise of 7 magnitudes below sky. Figure 2 shows a typical background map of a IIIaF UKSTU plate centred on NGC 3379 used to search for a low surface-brightness radio object (Schneider et al. 1983). No emission brighter than 27.2 magnitudes per sq. arc-second in R could be found which sets a lower limit on the mass-to-light ratio of the object at one.

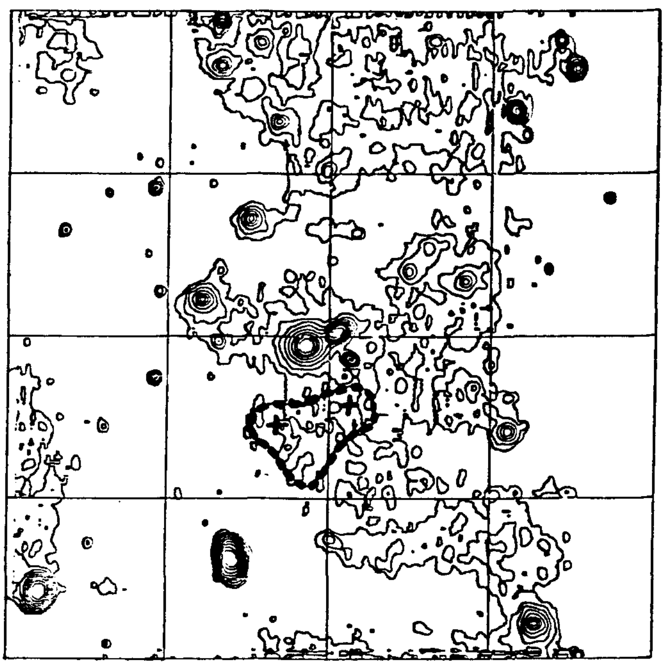

Figure 2. APM background map of an R plate centered on NGC 3379. Lowest contour corresponds to 27.2 mag/sq. arc-sec in R. Dotted line marks the position of the radio galaxy. The map covers 140 arc-min square.

A whole Schmidt plate can be scanned in this background mode in three hours and is extremely powerful for the automated detection of low surface-brightness galaxies. We have already catalogued these objects for Fornax (Cawson 1983) and are starting work on Virgo. At these low light levels the photographic plate is extremely linear, and accurate measurements can be made even in the presence of large-scale photographic non-uniformities.

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Rotation of the Galaxy

One of the most interesting current projects is the determination of absolute proper motions of stars by using distant galaxies to define the reference-frame. Provided the centre of the galaxies are not saturated - which is the case for the majority of galaxies on a Schmidt plate - the positional accuracy of their measured centres turns out to be almost independent of their size and of the plate-scale.

Measurements of galaxy positions on Schmidt plates have an rms error of about one third arc-second so that the reference-frame can only be determined to $\approx 1/\sqrt{N}$ arc-seconds where N is the number of galaxies used for the plate-solution. Projects such as the Lick astrographic survey which have only a few dozen galaxies to define the co-ordinate system need a large number of plates to attain the required accuracy, and systematic effects due to the intrinsic differences in the shapes of galaxies, to photographic non-linearities and to colour-terms dominate. In the APM proper motion survey 30,000 galaxies are used to define the reference-rame and the field is measured in two colours. The galaxies

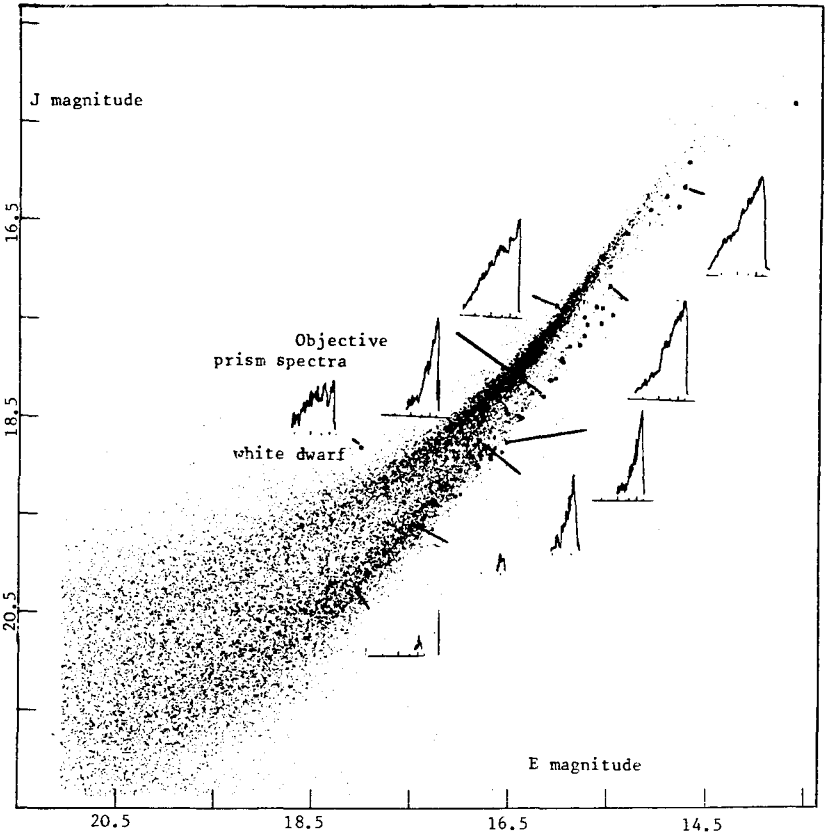

Figure 3a. Colour diagram of stars measured on the APM machine. Squares mark high proper motion (0.05 arc-sec/year) objects. Representative spectra are shown.

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are distributed uniformly over the field and by using a 12-parameter plate-solution we can take out second-order differential refraction effects across the field of the Schmidt. 30,000 galaxies define the reference-frame to a few milli-arc-seconds and the importance of having large numbers of galaxies cannot be overstressed. Stars of approximately the same colour as the galaxies are chosen (K stars) by measuring a red and blue plate (Figure 3a), and the mean proper motion as a function of apparent magnitude is determined. This project has so far been carried out in only one field (8h 53, +17 34) at 1=209 and we intend to determine the proper motion for a number of different galactic co-ordinates. Figure 3b shows the mean proper motion as a function of distance determined photometrically for groups of K stars of the same magnitude. This gives a formal value of (A cos 2 1 + B) of 0.00041 arc-seconds per year. Corrections have to be made for the non-zero galactic latitude and better photometry bas to be obtained (so far the distance scale has only been determined from internal calibration of the data) but the experimental error of the proper motions is genuine and is less than one milli-arc-second per year per plate-pair. We expect to be able to reduce this to 0.2 milli-arc-second per year using E-copy plates and will measure Oort's constants to a few per cent. The accuracy of the technique is sufficiently high that the proper motions of the Magellanic Clouds and local galaxies out to Carina could be measured.

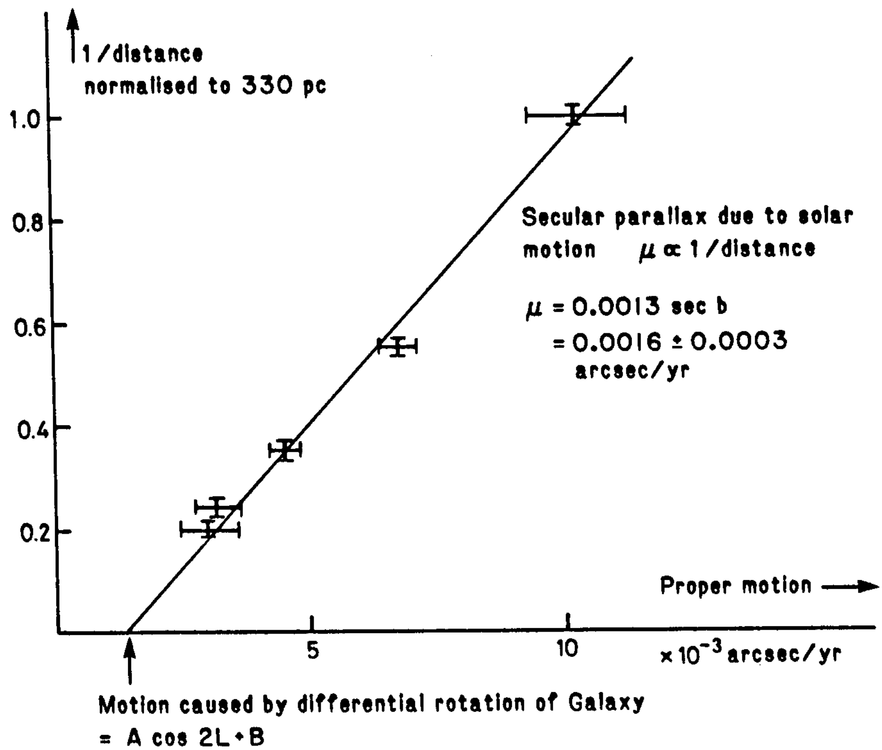

Figure 3b. Secular proper motion of K stars as a function of distance from the Sun. The slope is a measure of the solar motion.

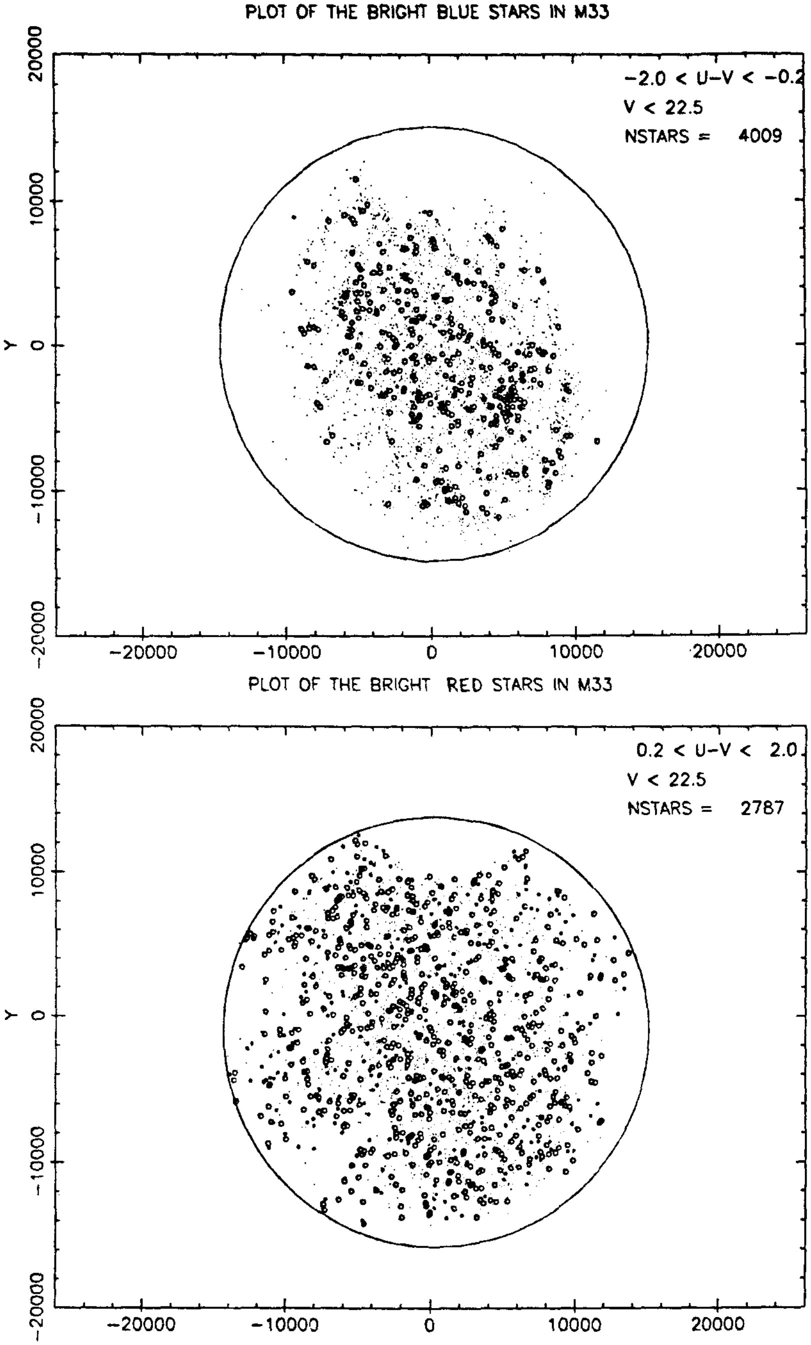

Figure 4. Red and blue stars discovered in M33 by APM machine. Circle defines the unvignetted field.

Bright Stars in Nearby Galaxies

The background correction of the APM system is sufficiently good that accurate photometry of bright stars within nearby galaxies can be routinely determined. Wendy Freedman and Barry Madore have measured and analysed M33, NGC 300, NGC 2403, M81 and M101 in 6 weeks this summer. Pete Bunclark will be talking about his calibration routines in this conference which use the measured areal profile of the stellar images and convert measured APM integrated intensities into a number directly proportional to magnitude over a range of at least ten magnitudes. A substantial fraction of the scatter is due to photo-electric photometry in the presence of the galaxy background.

UBV colours of 10,000 stars down to 22 magnitude were measured from a set of CFH prime-focus plates of M33. Figure 4 compares the distribution of the blue stars, which mainly form within the spiral arms, with the red stars which are either field stars or old red giants and are more uniformly distributed.

Supernova Search

The unique feature of the APM system in Raster-90 Mode - being able to scan a sequence of images from right ascension and declination positions - allows the system to be used for a fully automated supernova search.

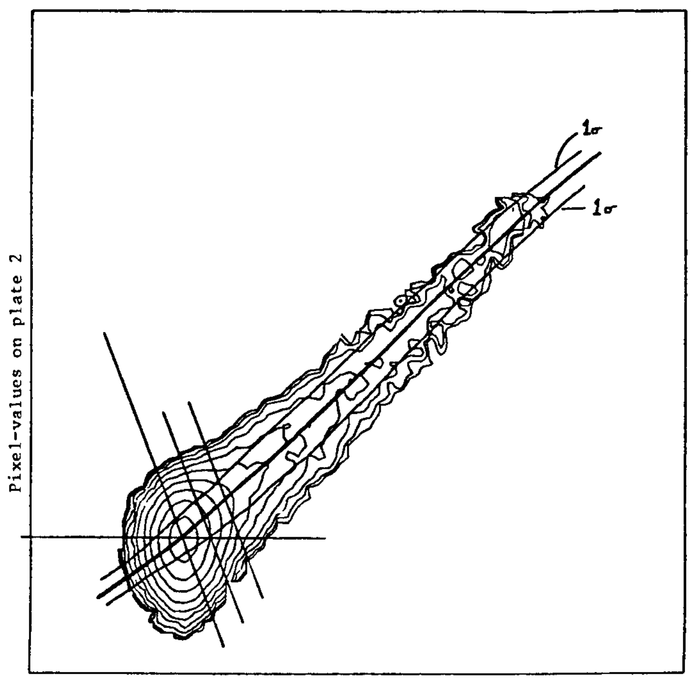

Figure 5. Calibration Mapping (see text).

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Image Mode is first used to parameterise all the images within the search field from which the galaxies are chosen on the basis of surface brightness. The right ascensions and declinations of the galaxies are stored on disc and a 90 x 90 raster scan of each one is made. Subsequent plates are also scanned in Raster-90 Mode which operates at about 600 scans per hour. Early and late epoch scans are analysed off-line to search for supernovae. However, before scans can be subtracted they have to be calibrated and this is achieved by a statistical method of Calibration Mapping (Cawson 1983) which uses the data itself to remove possible differences in the photographic response of the two plates. Figure 5 shows a scattergram of pixel-values on one plate against corresponding values on the other plate. The curve of maximum density through the scattergram maps corresponding pixel-values onto the same scale enabling a flat difference-frame to be produced. This is analysed for groups of connected pixels with a significant difference and enables supernovae to be detected right to the centres of galaxies.

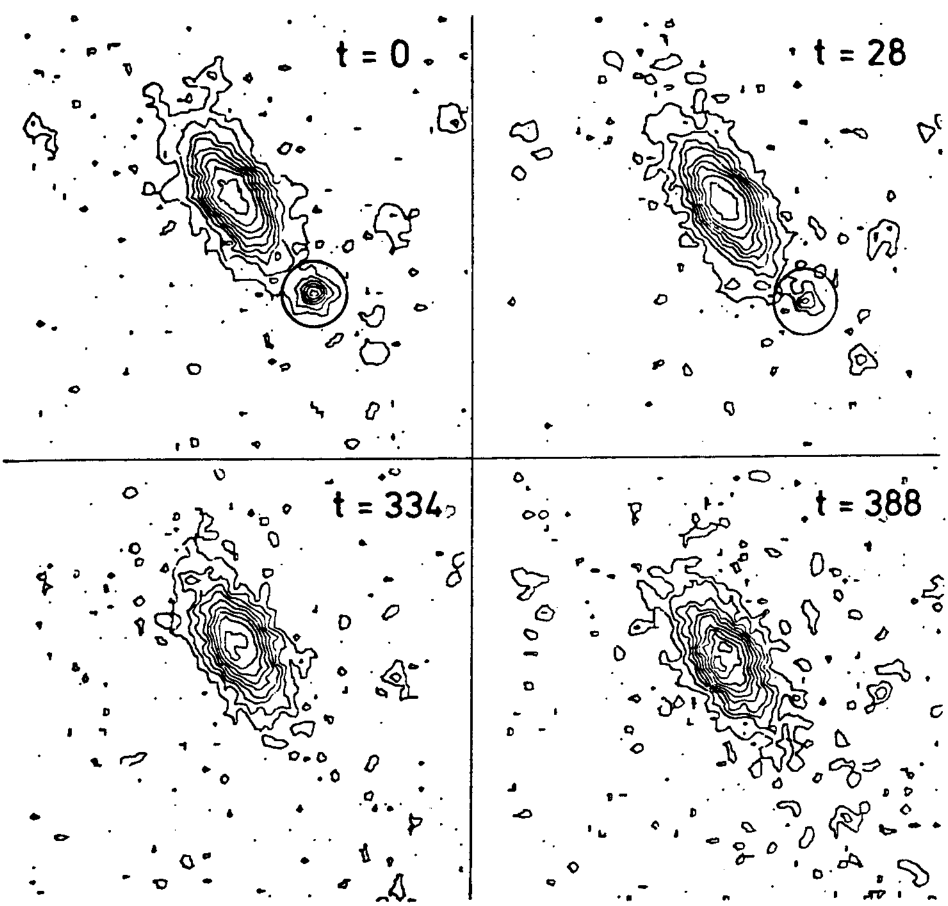

Figure 6. Contour plots of a supernova discovered automatically with the APM machine. Times are in days.

So far four supernovae have been found on a set of four UK Schmidt Telescope plates of area 406 (22h 48, -35). Figure 6 shows a contour plot of one of the supernovae on each of the four plates.

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