THE DETECTION OF FAINT IMAGES AGAINST THE SKY BACKGROUND

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INTRODUCTION

This title was first used by William Baum (1955) in his contribution to an IAU Joint Discussion on photoelectric image tubes and their astronomical applications. The general tone of the ten or so papers collected in the 1955 IAU Transactions was optimistic. It seemed quite clear that the high quantum efficiency of the electronic devices existing at the time would soon be turned to astronomical advantage and that objects much fainter than those detectable photographically were well within reach.

This period was a time when the concepts of signal-to-noise ratio and quantum efficiency were being extended to detectors of all kinds, mainly as a result of the work of Rose (1946). The photographic aspects were persued by Jones (1958) and Fellgett (1958) who emphasised that in a given image area a fine grained emulsion could count more photons than a coarse grained one, thus improving the signal-to-noise ratio of the image. The practical consequences of this were appreciated even earlier; in 1955 Baum was able to write:
'In principle we should be able ----- to place a fine-grain plate at the prime focus of the 200" telescope, expose it night after night on the same field, and eventually reach the same threshold of detection which an image tube system would yield ----. In practice, of course, reciprocity failure and the cost of telescope time would make such a procedure abortive'. Ten years later, Marchant and Millikan (1965) of the Eastman Kodak Company had evolved just such an emulsion and, initially at least, exposure times were inconveniently long, though not everyone was deterred by this. Of one of the first astronomical exposures with the new emulsion, Sandage and Miller (1966) say:
'The results were remarkable. A vast number of galaxies were visible over the entire plate - galaxies invisible on 103aO and 103aE plates exposed to the sky limit'. This fine grain, high contrast emulsion, now known as IIIaJ, was extremely slow but responded well to the hypersensitising techniques under investigation at the time. These techniques largely remove the bogey of reciprocity failure as well as giving a real

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increase in sensitivity, thus allaying Baum's fears of prohibitively long exposure times. With careful hypersensitising the IIIa emission can be exposed to yield maximum output signal-to-noise (i.e., the sky-limited condition) in 60 minutes or so on an f/3 telescope, much shorter than the several nights anticipated by Baum in 1955.

His paper contains several ideas which were to be developed more fully in a better-known publication, his contribution to Hiltner's Astronomical Techniques (Baum, 1962). One idea however was dropped. That was something which he described as amplification and background subtraction and which to Baum (1955) 'does not seem photographically feasible'. This idea has in fact proved to be an extremely powerful method for detecting faint objects against the night sky, especially in combination with fine-grained emulsions exposed to the sky limit. The method is used to produce contact derivatives from original plates by means of a high contrast film in conjunction with a diffuse light source (Malin 1978a) and has been further developed to incorporate multiple-image superimposition, (Malin 1981) unsharp masking (Malin 1977, 1979) and as a means of making colour photographs of very faint objects (Malin 1980). Since the 1.2m Schmidt telescope (UKST) is a convenient source of sky-limited plates of excellent quality, it is natural that these photographic techniques should be applied to them. This paper briefly describes some of the results obtained, in the main from Schmidt material, but often followed up by plates from the 3.9m Anglo-Australian Telescope (AAT).

PHOTOGRAPHIC AMPLIFICATION

The purpose of photographic amplification is to enhance the visibility of faint photographic images. There are many ways to accomplish this of which the various methods of chemical intensification are perhaps the best known. Haist (1979) gives a thorough coverage of these possibilities. More complex methods of faint image enhancement by means of radioactive toners (Askins 1976) and 20 MeV electrons (Murray 1980) have also been tried. All these methods involve some chemical after-treatment of the processed emulsion but their main disadvantage is that they enhance background as well as image, which is why Baum (1955) dismissed this type of amplification for deep astronomical plates where the uniform density due to sky and chemical fog is already very high.

An alternative process, developed by Malin (1978a) is a non-destructive contact-copying procedure, which uses high contrast film. The copy exposure is adjusted so that only a very small range of densities around the sky background of the original plate appear on the copy positive. The sky background is not so much subtracted (to use Baum's terminology) as ignored and the increased contrast enhances the detection of faint objects superimposed upon the sky background density. There are other subtleties, mainly concerned with the use of a diffuse light source; these have been discussed elsewhere (Malin 1982). The high contrast but low density film positives produced by this process are printed on to contrasty bromide paper to produce the negative prints preferred for faint object detection. This very simple technique has revealed many new, low surface brightness structures, some of which are illustrated by the following examples.

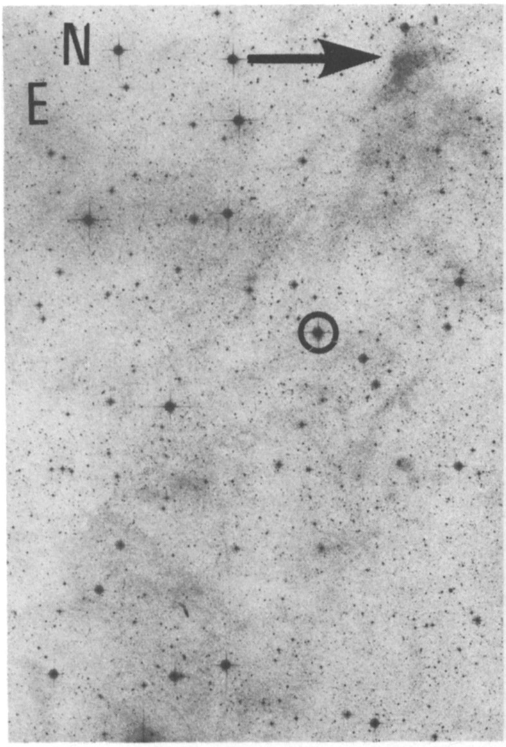

Fig 1. Extensive faint nebulosity has been found in several UKST plates centered near the SGP. The arrow indicates the only patch visible on the original. The circled star is SAO 166722, near 0^h 56.7 -25° 13 (1950).

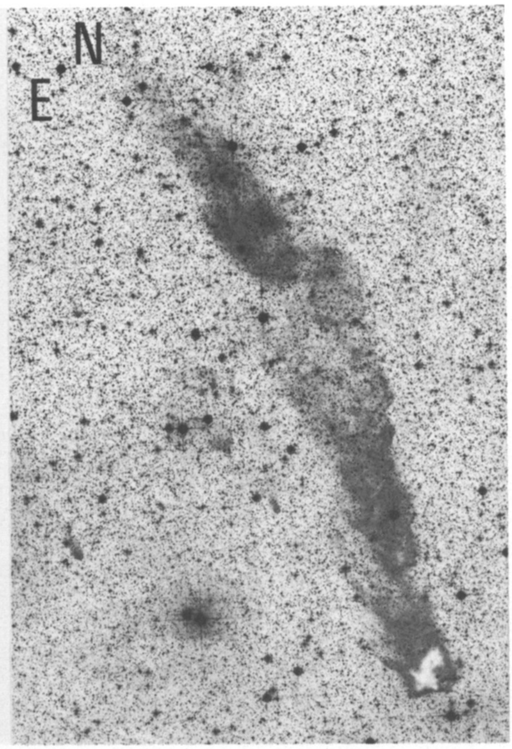

Fig 2. About 7 faint cometary globules can be seen on this photographically amplified derivative from a deep IIIaJ Schmidt plate. Figs 1 and 2 are the same scale. The vertical height of each print is about 1.5°.

NEBULOSITY NEAR THE SOUTH GALACTIC POLE

During routine quality control inspections of plates at the UKST, Sue Tritton noticed that several plates of regions near the South Galactic Pole (SGP) showed evidence of very low contrast non-uniformities apparently covering small regions of the 6 x 6" fields. These effects were only visible to the experienced eye and would have passed unseen in regions of higher stellar density. When new plates of these fields were obtained, the non-uniformities remained. Photographic amplification of the plates showed that some fields were filled with extensive but very faint filamentary nebulosity. Although no detailed investigation of this nebulosity has been attempted, in view of its structure and distribution, it seems likely to be evidence of an extensive dust cloud which is reflecting light from the Galactic disc. Naturally, if such a cloud can reflect light from within the galaxy, it can attenuate light from beyond it, with obvious implications for those who study the luminosity, distribution and colour of faint objects in the direction of the SGP. The SGP itself seems clear of nebulosity, but the filaments seen in Fig. 1 can be traced to within 3° of the pole on the eastern side. Fig. 1 covers an area of sky about 1 x 1.5°.

The arrowed region of nebulosity, burned-out in this reproduction, is just visible to the unaided eye on the original plate. From previous quantitative work on faint features (Carter et al 1982) we estimate that the surface brightness of the indicated patch is about 26.5 mag arc sec^{-2} in B and that the faintest wisps visible in Fig 1 are about 1-1.5 magnitudes fainter.

COMETARY GLOBULES

Cometary globules appear to be a variety or perhaps a precursor of the well known dark clouds often identified as Bok globules. Cometary globules are distinguished by their long, faintly luminous tails extending from compact dusty heads, the whole object often spanning more than 1 degree of sky. They were first noted by Hawarden and Brand (1976) on deep IIIaJ plates taken on the UKST and have been studied by Zealey (1979) and Reipurth (1982).

Cometary globule (GG) number 22 in Zealey's list is quite easy to see on the original SRC IIIaJ plate, but the full extent of the tail is only apparent after photographic amplification (Fig 2). Also revealed by this process are several other, much smaller tails without any evidence of dark clouds at their origin. Like CG 22, these tails point in the general direction of the extremely luminous stars towards the centre of the Gum Nebula. At least seven such nebulous objects can be seen on the original print of Fig 2. Other examples of photographic amplification applied to Galactic objects appear in publications by Malin (1978a) Elliott and Malin (1979), Zealey et al (1980) and Gilmozzi et al (1983).

GALAXIES

The photographic amplification technique has proved to be particularly useful for determining the extent and structure of galaxies. Fig 3 indicates why this is so. Fig 3a is a normal contrast copy, representing the visual appearance of a deep IIIaJ plate taken on the UKST. Fig 3b is the result obtained by the photographic enhancement of this same plate. The galaxies are the well-known group in Leo which includes NGC 3379, the prominent E1 galaxy which has been adopted as a luminosity distribution standard.

This galaxy has been the subject of a detailed photometric study by de Vaucouleurs and Capaccioli (1979) who have obtained an expression for the luminosity profile of the galaxy to very faint limits. On the enhanced print, Fig 3b, the envelope of the galaxy can be detected out to at least 6.7 arc sec on either side of the nucleus in an EW direction, which corresponds to a surface brightness of 27.5 mag arc sec^{-2} on the basis of the de Vaucouleurs-Capaccioli profile (in B; the photometric correction from B to (IIIa)J is small and has been ignored here).

On the night the plate was taken, (1980 Jan 16) the UKST photoelectric sky photometer indicated that the sky in the direction of NGC 3379 was particularly bright, probably due to the combined effects of enhanced airglow near solar maximum and haze from bushfires burning in the nearby Pilliga Scrub (Dawe, private communication). The galaxy crossed the meridian during the exposure, culminating at a zenith distance of 44°N. The observing record shows that the night sky brightness varied from 22.16 (B, mag arc sec^{-2}) at the start of the 65 minute exposure to 22.04 at the end, which coincided with the start of twilight. If we take the mean night sky brightness as 22.1 during the exposure, then the faintest extremities of NGC 3379 as revealed on Fig 3b are 5.4 magnitudes fainter than the night sky. From this it seems evident that the photographic technique should be capable of detecting diffuse features as faint as 28.5 (B) mag arc sec^{-2} on plates taken under darker conditions, perhaps even fainter if there is an abrupt change in the luminosity profile of a faint object - a sharp-edged shell galaxy for example.

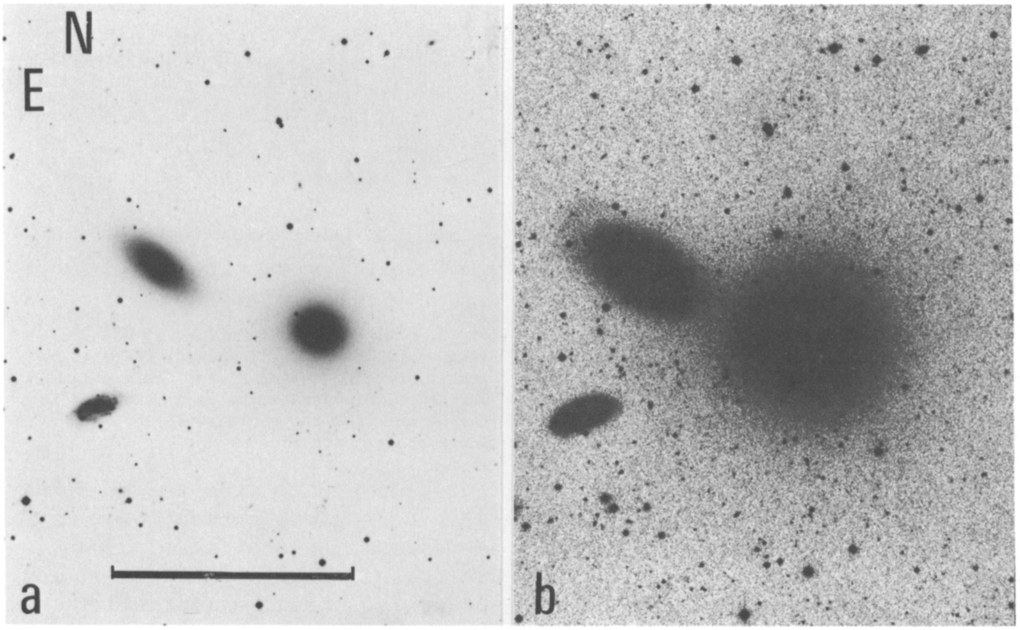

Fig 3. The NGC 3379 group of galaxies in Leo. Fig 3a represents the visual appearance of the original IIIaJ UKST plate while 3b shows the image derived from the same plate by the photographic amplification process. This shows features 5.4 magnitudes fainter than the night sky, including evidence of disturbance of the outer envelope of NGC 3384, the SO galaxy N.E. of NGC 3379. Scale bar = 10 arc min.

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Fig 3b confirms the overlap of the fainter isophotes of NGC 3379 with those of the SO galaxy NGC 3384 to the NE of it as described by Barbon, Capaccioli and Terenghi (1975) who do not consider this to be the result of interaction between the two. It should be noted however that the NE end of NGC 3384 is disturbed, with a faint diffuse loop or extension clearly visible on the deeper photograph. Fig 3b also neatly demonstrates in a qualitative way the marked difference between the luminosity profiles of the three main galaxy types. (NGC 3389, E of NGC 3379 is an SAS 5 galaxy).

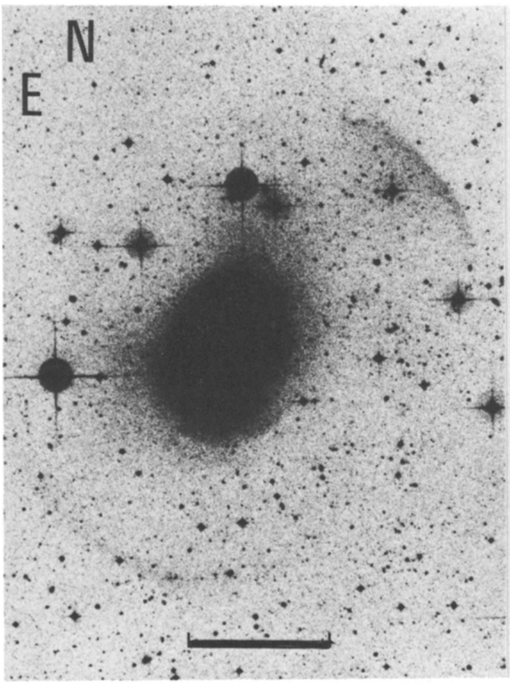

Fig 4. NGC 1344 was the first galaxy found to have a faint external shell. This photograph was made by combining the images of three UKST plates. The brightest part of the N.E. shell has a surface brightness of 26.5 mag arc sec^{-2} (B). Scale bar = 5 arc min.

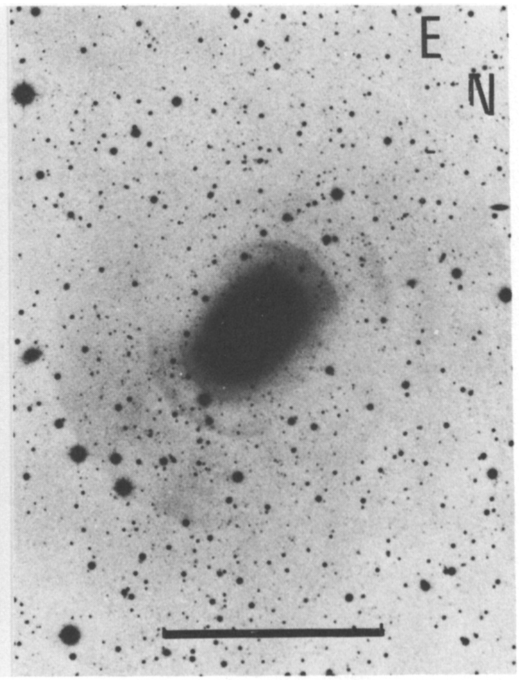

Fig 5. The internal structure of NGC 3923, another prominent shell galaxy, revealed by unsharp masking an AAT plate. This galaxy has about 18 separate shells interleaved in radius out from the nucleus. Scale bar = 5 arc min.

The ready availability of excellent deep plates from the UK Schmidt, and our tendency to apply non destructive photographic techniques to them on an almost routine basis, has led to several interesting findings. Perhaps the most important of these was the discovery of a pair of low surface-brightness shells around the otherwise normal elliptical galaxy, NGC 1344 (Fig 4). This was soon followed by the detection of similar shells around several other elliptical galaxies by Malin and Carter (1980). Subsequent work by Carter et al (1982) has shown that in the case of NGC 1344, which seems to be the best example seen to date, the shell is composed of stars of colours consistent with spectral type G5-K4. In the same investigation, using optical and infra-red photometry,

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it was found that the brightest part of the NW shell of NGC 1344 had a surface brightness of 26.5 mag arc sec^{-2} in B. This shell was just visible to the educated eye on the original IIIaJ discovery plate.

The observation that the brighter shell-type galaxies could be found by direct inspection without photographic enhancement encouraged us to visually inspect each of the 606 6 x 6° fields of the SRC J sky survey south of -20° in the form of film copies, searching specifically for elliptical galaxies which showed a shell-like structure. 137 such galaxies were found and their positions and a brief description of each has been published in the form of a catalogue by Malin and Carter (1983).

The statistical properties of this sample of elliptical galaxies are of interest. About half of them appear to be isolated, while another third are members of small groups with 2-5 members. Only 5 examples (3.6% of the sample) are found in clusters or rich groups. This distribution is of course quite unlike that of normal ellipticals which are generally gregarious. Another significant finding is that only two members of the sample - Fornax A and Centaurus A - are powerful radio sources. The shells in Fornax A, NGC 1316, have been described in detail by Schweizer (1980) while those in Centaurus A (NGC 5128) are the subject of a recent paper by Malin et al (1983).

The nature and origin of the shells has been the subject of some speculation, but Quinn's (1982) thesis, which predicted that shells would be produced as a result of the merger of a disc galaxy and an elliptical, seems to fit the observed facts quite well. It would be expected, for instance, that shells at a considerable distance from the nucleus of the parent galaxy would be readily disrupted by tidal encounters with group members if it were in a cluster whereas the shell would be more stable if the galaxy was isolated. Quinn's theory also predicts that a series of concentric shells might be produced during the merger, each interleaved in radius outwards from the nucleus. Some examples of this have now been seen; NGC 3923 (Fig 5) is the best so far found, where about 18 shells can be counted. Fig 5 was prepared by copying an AAT plate through an unsharp mask (discussed later).

Some observational evidence for galaxy mergers has been presented by Schweizer (1983) who lists 32 galaxies he considers to be possible merger remnants on the basis of their morphology (internal ripples, tails, isophotal twists etc). 10 of these galaxies also appear in the Malin-Carter catalogue. Schweizer has obtained CTIO 4m plates of some of the galaxies in his list and one of these, IC 3370, shows crossed streamers forming an 'X' and 'ripples' in opposite quadrants of the X. The cruciform shape is clearly seen in Fig 6a but a much deeper photograph, made from high contrast derivatives from three deep IIIaJ plates (Fig 6b) shows the debris left over from what is almost certainly a merger. This kind of amorphous, low surface brightness material has been seen associated with several of the shell-type galaxies in the Malin-Carter catalogue.

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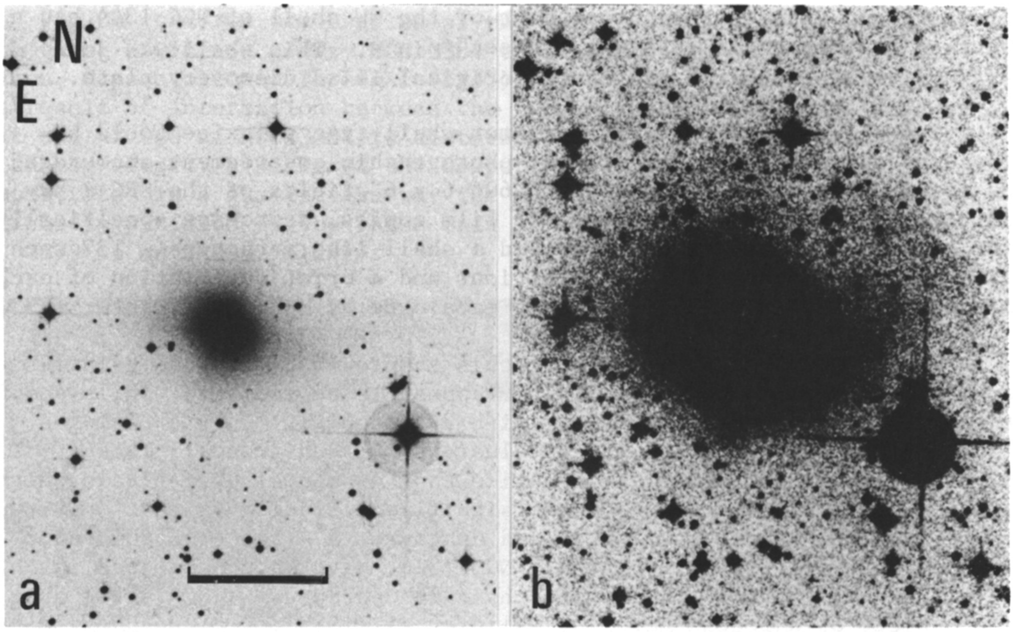

Fig 6. IC 3370 was identified by Schweizer (1983) as a merger remnant from the curious 'X' morphology of the galaxy seen in Fig 6a. A deeper image from three deep UKST plates reveals some of the debris of that merger. Scale bar = 2 arc min.

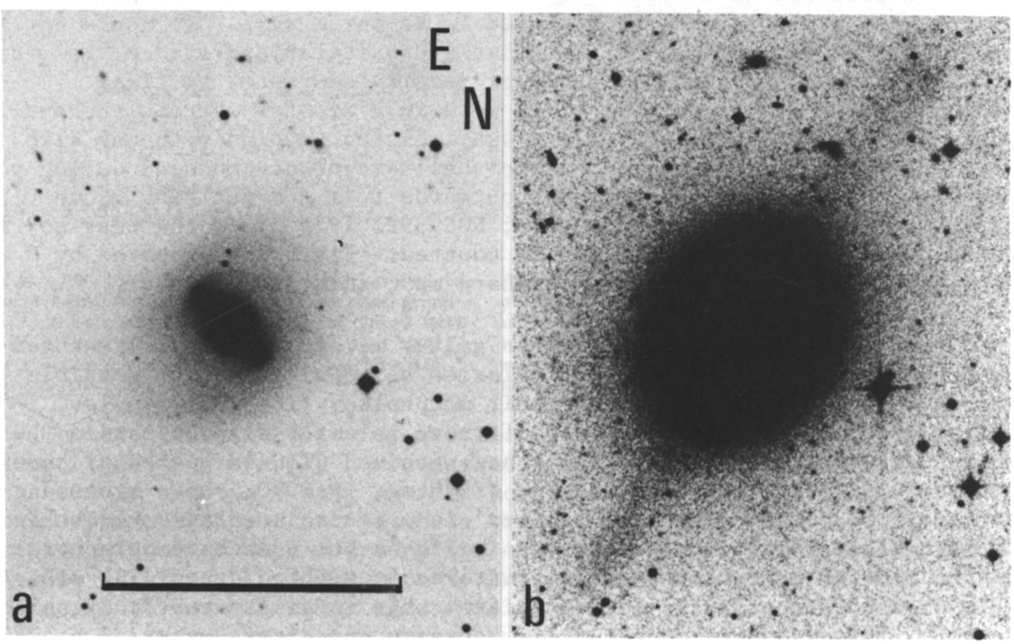

Fig 7. NGC 4643 appears to be a perfectly normal barred spiral on simple inspection of a deep UKST IIIaJ plate (Fig 7a). Only after photographic amplification are the remarkable extensions of the outer envelope visible (Fig 7b). Scale bar = 5 arc min.

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While the photographic enhancement of images of elliptical galaxies has been particularly fruitful (for other examples see Malin 1981a and b) disc-type galaxies may also reveal unexpected features. The barred spiral NGC 4643 appears to be a perfectly normal galaxy seen almost face-on, with a very well developed bar running roughly NW-SE through the nuclear bulge (Fig 7a). A print made from the same SRC IIIaJ original, designed to reveal the faintest features (Figure 7b) shows that the galaxy has a large diffuse envelope, which has a radial luminosity profile more like that of an elliptical galaxy than a spiral (compare Fig 3b). Even more surprising are the two faint ansae which project from the diffuse envelope at right angles to the inner bar. We are not aware of any other galaxy which shows features of this type, which are quite unexpected. Note that the apparent angular extent of the galaxy has increased from about 4 arc min in (a) to over 10 arc min in (b). Although NGC 4643 seems to be a member of the southern extension of the Virgo cluster, no other galaxy appears to be near enough to cause the observed disturbance. Both the photographs in Fig 7 are printed with the same scale and orientation.

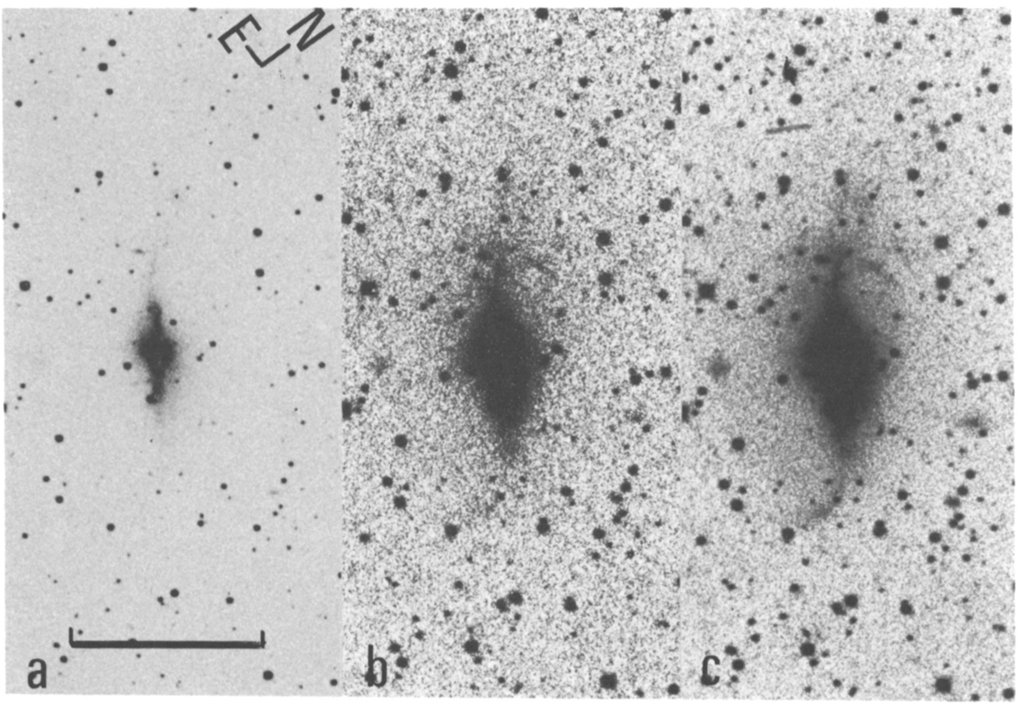

Fig 8. The effect of multiple-image superimposition on the signal-to-noise ratio is clearly seen in this series of photographs of NGC 4672. Fig 8a is derived from a greatly enlarged normal contrast copy of a deep UKST IIIaJ plate. The same plate produced the amplified version seen in (b). Although deeper, much fine detail is hidden in the grain noise. The effect of combining the amplified derivatives of four plates of similar quality is apparent in (c) where the galaxy is seen to be highly disturbed. Note that there is no loss of resolution in the image. The diameter of stars at the plate limit in (a) is the same as those at the limit in (c), though these latter are much fainter.
Scale bar = 2mm on the original plate.

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INTEGRATION PRINTING

The photographic amplification process described above enhances the apparent size of the silver grains which form the original image and the pictures produced always appear more grainy than those produced from normal copies. This effect is usually offset by a marked gain in the perception of faint images and is not obtrusive at modest enlargements. However, reduced granularity and improved perception of faint objects, particularly those with a scale length approaching the limit of resolution on Schmidt plates (e.g. stars) can be obtained by combining the images derived from two or more plates. This technique is always used to add together photographically amplified positives - there is little point in combining images which have not been enhanced to reveal the faintest information. The effect of this is seen in Fig 8. All three images are of the edge-on spiral NGC 4672 in the Centaurus cluster and are printed to the same scale, an enlargement of about 13x. Fig 8a is derived from a normal contrast copy of a deep IIIaJ plate while Fig 8b is the same image after photographic amplification. The effect of superimposing four high-contrast derivatives is shown in Fig 8c. Faint stars and low surface brightness features not seen in 8a and buried in the grain of 8b are seen clearly in Fig 8c. The improvement in signal-to-noise is evident and the disturbed outer structure of NGC 4672, only suspected from the appearance of Fig 8b, is amply confirmed in the four image superimposition. A simple device for combining multiple images has been described elsewhere (Malin 1980).

UNSHARP MASKING

In keeping with the title of this contribution, the previous sections have been concerned with the detection of faint images against the night sky. The photographic properties of fine grain and high contrast which are so useful in this endeavour inevitably have the disadvantage of limiting the dynamic range of the emulsion. In the case of IIIaJ plate exposed to the sky limit (i.e. minimum sky density of $\sim$ 1.0 ANSI above fog) the available dynamic range is about 1 log exposure unit or 2.5 stellar magnitudes before the emulsion saturates at its maximum density of $\sim$ 4.5. This compares with a dynamic range equivalent to 7.5 magnitudes and a maximum density of $\sim$ 1.6 for a normal commercial camera-speed material. This limitation is a serious problem when information on the bright interior of a galaxy or HII region is required and the only image available is on a sky-limited IIIa plate.

This difficulty can be overcome in part by adapting a process called unsharp masking, long known in the graphic arts industry, to the special needs of astronomy. The process has been described in detail by Malin (1977) but in essence it is the reverse of Baum's (1955) background subtraction. An unsharp film positive of the plate is prepared by contact copying the original on to film through the glass support. The developed positive is then used as a mask to subtract the coarse detail from the original, leaving faint and small scale structure largely unaltered. The effect of this is clear in Fig 9, where a direct print

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(a) from a deep UKST IIIaF plate of the Orion Nebula is compared with the unsharp masked version from the same plate (b). The technique has been particularly useful in exploring the dense images of elliptical galaxies, where low contrast structure is often hidden in the high density of the image of the elliptical envelope. (See Fig 5).

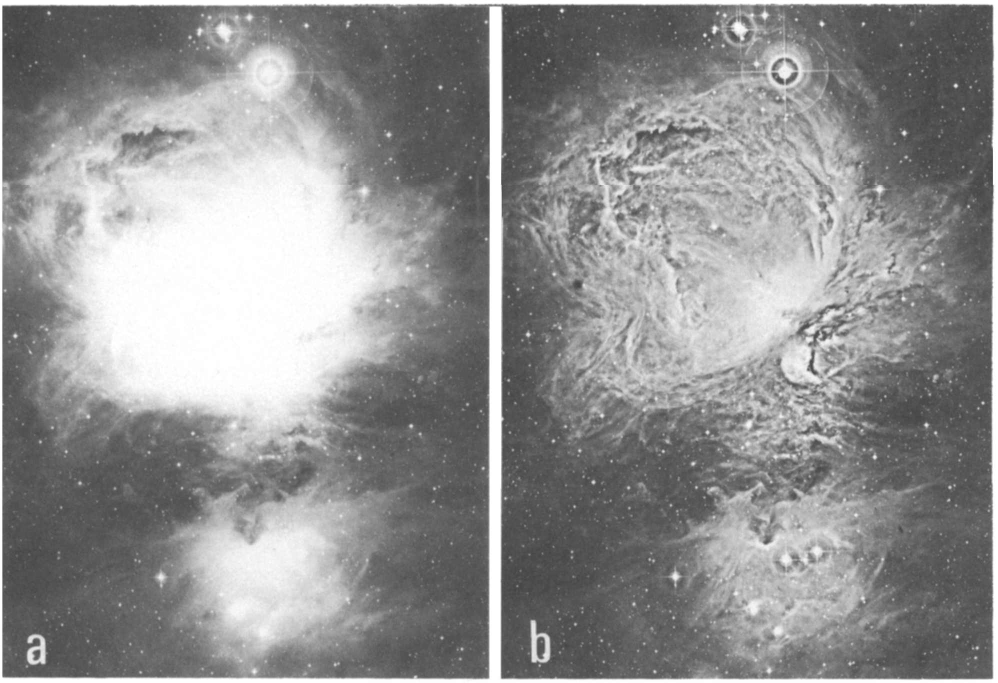

Fig 9. The effect of an unsharp mask on a deep UKST IIIaF plate of the Orion Nebula. Fig 9a is the best print which could be obtained by using the original plate as a negative in the enlarger. In Fig 9b much additional information appears. This details was hidden in the high density regions of the plate (D max 4.5) and was only revealed after printing through an unsharp mask in conjunction with a diffuse light source.

COLOUR PHOTOGRAPHY

The various processes of analogue image manipulation outlined above produce as a first derivative a positive film copy. Positive derivatives from separate plates taken in the standard photographic B,V and R pass-bands can be combined in the manner of James Clerk Maxwell to yield a 3-colour image representative of the true colours of the object. Such photographs show objects which are much too faint to be recorded by tri-pack colour films and reveal details of scientific as well as aesthetic interest. These pictures are now available in the form of 35mm slides (Malin 1983).

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PLATE UNIFORMITY, THE ULTIMATE LIMITATION ?

The methodical record-keeping and quality control procedures which were soon established at the UK Schmidt quite quickly traced and eliminated many of the more obvious causes of plate non-uniformity. Generally these defects were seen on simple inspection and arose from one or more of the numerous hazards of shipment, storage, handling, hypersensitisation, exposure, processing and drying which plates must undergo. While the effects were always detected without the aid of photographic enhancement, their causes were often difficult to trace or when traced, not easily eliminated. The high standard of the SRC deep southern survey is a tribute to the skill and dedication of successive members of the UKST group which produced the original plates substantially free from visual defects.

This achievement was even more impressive when the photographic amplification technique began to be applied to UKST plates. The technique is not selective - any small density difference is enhanced, no matter what its origin. This property makes this simple process into a powerful diagnostic aid for revealing and tracing artefacts which ultimately limit the detection of faint objects. Fortunately, most of the faint features discovered turned out to be real objects, but one type of non-uniformity appeared to some extent on almost every hypersensitised IIIa plate and will be discussed here as an example of the subtle problems to be encountered in faint object photography.

In the UK Schmidt telescope, the plate is curved about a radius of 3.07m and is (usually) positioned close to a flat glass filter. At the corner of the plate the air gap between the emulsion surface and filter is $\sim$ 11 mm, which narrows to only $\sim$ 3 mm at the centre. The natural convective flow of air within this space is therefore increasingly restricted towards the plate centre. It is known that dried, hypersensitised plates lose speed if they are allowed to stand in room air before or during a long exposure to light (Malin 1978b). This is probably due to the re-establishment of low intensity reciprocity failure (dehypersensitisation) by absorption of traces of water vapour and will be more pronounced where air circulation is greatest, i.e. near the edge of the plate in the Schmidt. The result is a radial gradient in sensitivity, with its greatest effect at the plate edge (Dawe and Metcalfe1982, Campbell 1982). On a IIIa plate exposed to the sky limit (density 1-1.3 above fog) the gradient can amount to a density difference of 0.1-0.15 from the centre to the edge of a 14x14 inch plate. While this is too small and gradual a change to be detected visually, its presence is obvious when a whole plate is photographically amplified and in our experience was, until recently the most obtrusive large-scale non-uniformity on hypersensitised IIIa plates from the UK Schmidt. This result is consistent with the work of Dawe, Coyte and Metcalfe (1983, in preparation) who found density differences from the plate centre to a radius of 107 mm ($\equiv$ 2°) equivalent to 0.05 magnitudes with small-scale point-to-point variation of $\pm\ 0\overset{m}{.}03$. Plateholders have recently been modified to overcome the problem by flowing nitrogen into the space

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between plate and filter during exposure. Preliminary results (Dawe, private communication) indicate a substantial improvement in both large and small scale plate uniformity together with a small increase in effective plate speed.

With the elimination of this last major user-induced problem, we are finally left with emulsion variations introduced in manufacture. Over the last 5 years or so, many plates from a variety of telescopes have been critically examined by photographic enhancement. Almost all the artefacts detected are originated by the user, very few seem to be the result of the manufacturing process. It should be emphasised that it is a remarkable achievement to manufacture and supply a detector 14 inches square which is able to detect variations in signal around the 1% level and which has a quantum efficiency of a few percent. And all this from an emulsion dewigned almost 20 years ago.

THE FUTURE

Over the last 100 years the development of astronomy and photography has been inextricably linked. Clear advances in astronomical understanding can be traced to the introduction of the dry gelatin plate in the 1880s, advances in dye sensitising in the 1920s and the introduction of Eastman Kodak spectroscopic plates in the 1930s, with special emulsions (type 'a') for long exposures appearing after the war. The last major improvement came with the introduction of the IIIa emulsion in 1965, though hydrogen hypersensitising (Babcock et al 1974) was necessary to make these products generally useful.

Major advances in emulsion making, as discussed in a recent Research Disclosure (Anon. 1983) indicate that substantial improvement in both the speed/granularity relationship and in the art of spectral sensitising have occurred in the last few years. These developments are appearing in improved colour negative and reversal materials now available from several manufacturers and stem largely from new methods of emulsion-making which give close control over the shape of the silver halide gain.

It is probable that some of the developments outlined in the Research Disclosure could be incorporated into a new generation of spectroscopic emulsion. With this possibility in mind, it might be useful to consider where improvements might best be realised, in granularity, speed or contrast, and what changes, (if any) in spectral sensitivity would best serve the astronomical community to the end of the century.

It is the personal view of this writer that the greatest gains will come from the photographic investigation of the faintest objects. For this, an emulsion with a (hypersensitised) speed and granularity similar to that of the current type IIIa, but with a much increased contrast level (γ = 5-7) is needed. Maximum output signal-to-noise might be achieved with less exposure if maximum contrast was attained at a lower density than is found in the present generation of IIIa products. Such an emulsion would have a very restricted useful dynamic range and an even smaller range over which output signal-to-noise is optimum, and users would be obliged to judge their exposures to within a few percent. This kind of control, which involves sensitometric tests on each batch of hypersensitised plates, has been the practice at both the UKST and the AAT for the past 6 years and has eliminated under- or over-exposure, with consequent saving of telescope time. An emulsion of increased contrast, optimally sensitised to the darkest part of the night sky and used in conjunction with enhancement techniques should reach 29.5 mag arc sec^{-2} at a dark site.

As a second option, a series of emulsions of much lower contrast, ($\gamma \sim 1.5$-2) sensitised in the photometric O, D and F bands and of much finer grain than the present IIa series would improve photographic photometry on small telescopes and be valuable for morphological studies of galaxies on Schmidt telescopes. Certain aspects of the art of spectral sensitising are specifically referred to as facilitated by the new emulsion technology described in the Research Disclosure. One area where such improvements might be of immediate benefit, particularly in objective prism work, is the design of an F sensitising with a much more uniform spectral response.

I emphasise that these are personal preferences and in no way reflect the views of the astronomical community as a whole. They are merely intended to stimulate discussion amongst those interested in furthering astronomical research with photographic detectors. There seems little doubt that with careful use, the present family of emulsions is equal and often greatly superior to any form of electronic detector for detecting faint images against the night sky background. The next generation of emulsions is keenly awaited.

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Comment by Russell Cannon during general discussion on Friday afternoon, relating to the discussion led by David Malin on new photographic emulsions.

I support nearly all of the points made by David Malin, but would like to enlarge on two matters. (i) Regarding possible increases in emulsion speed, it is important that we have a real gain and not simply a decrease in the time it takes to reach a given photographic density. In other words, we want to retain all the properties of the excellent IIIa-J emulsion, and in particular there must be no loss of resolution; thus a halving of exposure time 'to achieve the same results' means we want a real increase in DQE by a factor of two. Such an increase would surely be welcomed by all Schmidt astronomers.

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(ii) I think that Malin's plea for an increase in contrast is more of a specialist requirement, and to a certain extent will only produce yet more very faint features which are too faint to be studied further either photometrically or spectroscopically, as well as making a mess of more of our favourite galaxies, star clusters or whatever! More seriously, I suspect that when David says that he cannot get more out of the existing plates if he tries to push the copy contrast even higher because this simply brings up the grain, what he means is that his present techniques already extract all of the useful information from IIIa-J plates. Therefore what we need are not necessarily higher contrast original plates, but plates with a higher information content or better signal-to-noise; I think this must mean going to finer grain emulsions.

I would like to add my support to two other specific points: astronomers really would like to have a 'IIIa-O' emulsion for photometric work, and a flatter wavelength response version of the IIIa-F would be invaluable for objective prism spectroscopy.