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H I in Shell Galaxies and Other Merger Remnants

David Malin[1] and Brian Hadley[2]

[1] Anglo-Australian Observatory, PO Box 296, Epping, NSW 2121, Australia
dfm@aaoepp.aao.gov.au

[2] Royal Observatory, Edinburgh, Blackford Hill, Edinburgh, EH9 3HJ, UK

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Abstract: The few elliptical galaxies with detected H I almost all seem to have optical peculiarities as well, though these are often well hidden and require special image enhancement techniques to reveal them. In this paper we show several deep images of ellipticals with optical shells which are associated with H I, and suggest that mergers, or at least encounters with gas-rich galaxies, are responsible. We also show some disk galaxies with unusual faint extensions, some of them the kinds of interactions that may result in H I in ellipticals. These illustrations are drawn from an atlas of low surface brightness images of bright galaxies currently in preparation.

Keywords: galaxies: elliptical and lenticular — galaxies: interactions — galaxies: structure — galaxies: halos

1 Introduction

'Shell' galaxies typically are isolated, apparently normal elliptical galaxies. On closer examination, they reveal low contrast but quite abrupt changes in their optical luminosity profiles. Some have faint but distinctive, edge-brightened external arcs for which galaxies of this type are named. They are widely considered to be merger remnants, a view reinforced by the discovery that several shell galaxies contain or are associated with significant (i.e. detectable) amounts of neutral hydrogen, and some contain dust. However, neither dust nor gas are regarded as significant components of 'normal' elliptical galaxies, but deep optical imaging techniques show that many apparently normal ellipticals, which seem free from gas, dust *and* shells, have unexpected asymmetric low surface brightness features suggestive of interactions, supporting the view that many, perhaps most, elliptical galaxies are the result of multiple mergers. This view is reinforced by H I and optical evidence of ongoing merger activity in nearby galaxies.

Deep imaging is increasingly the domain of array detectors, but conventional photography still has an important role, especially in the detection of faint objects of large angular size. This is partly because the excellent uniformity of the photographic detector enables contrast enhancement of plates taken on dark sites to reveal very small signals against the uniform contribution from the sky (Malin 1978). In addition, all of the sky has now been recorded on fine-grain photographic emulsions that lend themselves to such processing, though not all the original plates, which are needed for this process, are readily accessible.

Fortunately, this is not the case in the southern hemisphere, and some parts of the southern sky have been recorded on many such exposures, mostly by the UK Schmidt Telescope of the Anglo-Australian Observatory. The plate archive at the Royal Observatory, Edinburgh is a valuable source of such image data. Most of the results reported here derive from UK Schmidt Telescope (UKST) material, and most of it is the result of photographically combining several deep, enhanced images of the same field. Details of this process are given in Malin (1988). The images presented here are components of a photographic atlas of faint features of bright galaxies, currently in preparation.

In this paper we will present several examples of galaxies where unusual, low surface brightness features are revealed which are strongly suggestive of merger activity, and several where these features are correlated with an H I detection. We will also present images of some other galaxy types where anomalous low surface brightness features are strongly suggestive of merger activity but where no H I data exist, a situation likely to be remedied by the proposed ATNF H I survey.

2 H I in Shell Galaxies

Though bright-rimmed shells seem to be uniquely associated with elliptical galaxies, other types of galaxies show peculiar structures that can only be explained by invoking some external influence, ranging from the accretion of gas from a companion to a full-scale merger. However, not all anomalous optical features can be explained in this way (e.g. NGC 1313, Ryder et al. 1995) and not all galaxies that show such structures have detectable H I or obvious dust. Equally, not all elliptical galaxies with detected H I are optically abnormal. Here we will look at some examples of H I ellipticals, with and without shells.

One of the best examples of a shell galaxy with neutral hydrogen is NGC 5128, Centaurus A. In addition to its distinctive dust lanes, it has an extensive low surface brightness optical structure which extends well beyond the shell structure discovered by Malin, Quinn & Graham (1983). The location and spacing of the shells, together with a model of the shell-forming process, permitted some estimate of the age of the merging event that produced them. In the case of NGC 5128, using Quinn's (1984) model, it was shown that this was a few times 10^9 years ago. However, it seems probable that the faint outer material noted by Johnson (1963) and shown in Malin (1981) was displaced at some earlier period, perhaps by the current merger victim on a previous close passage. This faint outer envelope extends well over 80 arcmin along the NE–SW axis of the galaxy, and no distinct shell structure is visible, though it is not completely featureless.

Schiminovich et al. (1994) mapped the distribution of H I around the central 30 arcmin (about 30 kpc) of the galaxy, detecting $1 \cdot 5 \times 10^8\ M_\odot$ of H I, which seems loosely associated with the outermost shells, and noting that it appears beyond the optical boundary of the shell in each case where it is found. From the spatial distribution and velocity structure, they suggested that it forms a partial ring, and questioned the 10^9 year timescale for the merger derived by Malin et al. (1983).

NGC 2685 is another shell galaxy that was included in the original Malin–Carter (Malin & Carter 1983) catalogue. Schiminovich et al. (1995) have shown that the mass of neutral hydrogen it contains is similar to that found in NGC 5128, and it is likewise distributed in a large loop or arc, loosely associated with, but just beyond, the low-contrast optical features. A deeper image of this galaxy is included here as Figure 1. (All images in this paper are oriented with NE at the top left.) If the H I found in these galaxies is associated with the shells, the velocities are difficult to reconcile with any of the current shell-producing models. Clearly, H I observations are vital new evidence that can be used to refine models of shell formation.

NGC 5266 is a polar ring galaxy where the polar ring is hidden on deep exposures. However, the low surface brightness envelope is unusually large, and subtle evidence of the dust lane can be seen in the 'pinched waist' of the galaxy, which is noticeable on the original of Figure 2. This illustration also reveals an even fainter, smooth extension to the SE of the galaxy. Observations by Morganti et al. and Sadler (1997, present issue pp. 45 & 89) show that the optical extensions coincide quite well with the H I detection.

NGC 5018 (mentioned in Schiminovich et al. 1994) is an E3–E4 giant elliptical galaxy that was included in the Malin–Carter (1983) shell galaxy catalogue. Deep images show that it is obviously distorted and interacting with a gas-rich spiral companion, NGC 5022, with a faint, probably stellar 'bridge' between the two bright galaxies, clearly shown for the first time in Figure 3.

Though NGC 5018 itself has only a marginal H I detection coincident with the optical image, NGC 5022 has an extension of its H I profile in the direction of the giant elliptical (Kim et al. 1988). This coincides with the brightest part of the stellar bridge between the galaxies. These authors also showed that there are three blobs of H I with masses of a few times $10^8\ M_\odot$ (and velocities which are similar to those of both galaxies) in the field around NGC 5018, though they were only able to identify two with extended optical counterparts. Our deep image reveals that Kim's source S3 is also a galaxy (arrowed in Figure 3) which is featureless and of low surface brightness. Other low surface brightness galaxies which correspond to marginal H I detections are also indicated with arrows and all are probably members of a small group associated with NGC 5018/22.

Kim et al. described NGC 5018 as perhaps being 'caught in the act' of acquiring its H I from a companion galaxy; however, the galaxy has a dust lane (Fort et al. 1986) which seems to be deeply embedded, and an unusually low metallicity for a giant elliptical of this intrinsic luminosity. Bertola, Burstein & Buson (1993) consider the galaxy to be prototypical of a class of low-metallicity giant ellipticals. In view of the unusual juxtaposition of low metallicity and evident dust, it seems probable that these galaxies have interacted more than once, perhaps resulting in the shells and the material which produced the arc of H I-rich companions, but they are now in the early stages of a closer encounter.

Other optically interesting elliptical galaxies with detected H I are IC 1459, which appears to be an S0 but shows low-contrast spiral arms and a counter-rotating core (illustrated in Malin 1985) and the interacting pair NGC 1549–1553 (in Malin & Carter 1983). All these galaxies seem to be examples of 'galaxy harassment' of the kind described by Moore et al. (1996), where multiple, high-speed encounters drive star formation and leave detectable arcs of debris. These interactions will also leave disturbed spirals.

3 Spiral Galaxies with Unusual Faint Features

Here we present examples of gas-rich galaxies without obvious interactions or companions that nonetheless show evidence of interaction. A nearby example is NGC 253, in the Sculptor group. The extent of the optical halo of this galaxy is much

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Fig 1.

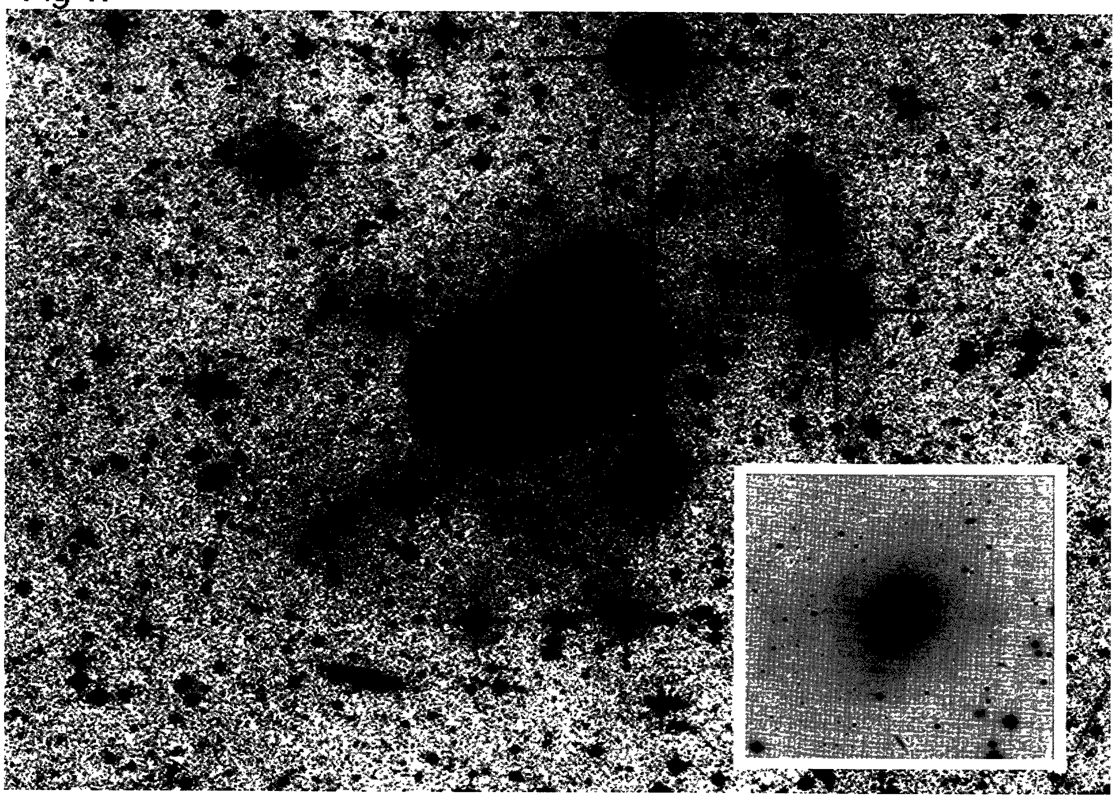

Fig 2.

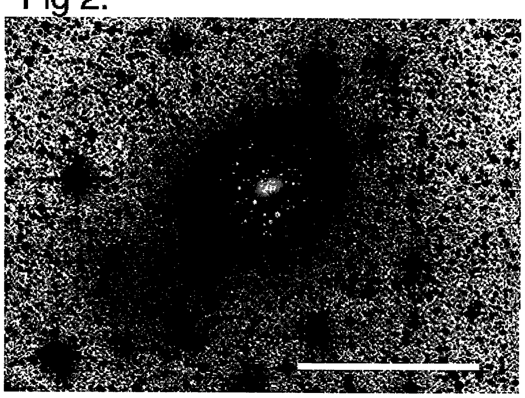

Fig 3.

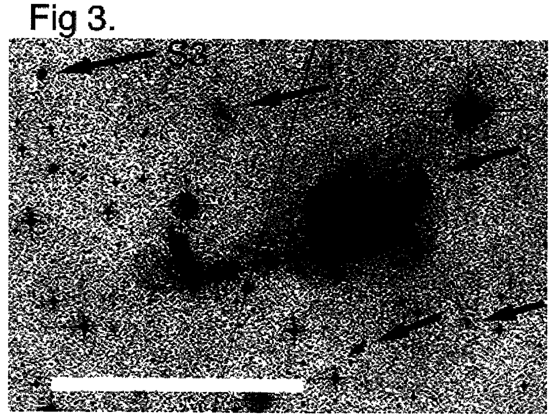

Figure 1—The main image of NGC 2685 was made by combining photographically amplified derivatives from three UKST IIIa-J plates and shows a series of low surface brightness loops extending from the galaxy. Inset is a normal contrast photograph of NGC 2865 made to the same scale. The inset print is 5 arcmin on a side.

Figure 2—This image shows the enormous extent of the faint outer envelope of NGC 5266 compared with the superimposed positive, which is to the same scale. Note the large, faint, structureless SE extension. The scale bar is 5 arcmin.

Figure 3—The interacting system NGC 5018/22 is clearly linked by a low surface brightness 'bridge' of luminous material. The arrows indicate the optical detection of companion dwarf galaxies detected in H I by Kim et al. (1988). Scale bar is 10 arcmin.

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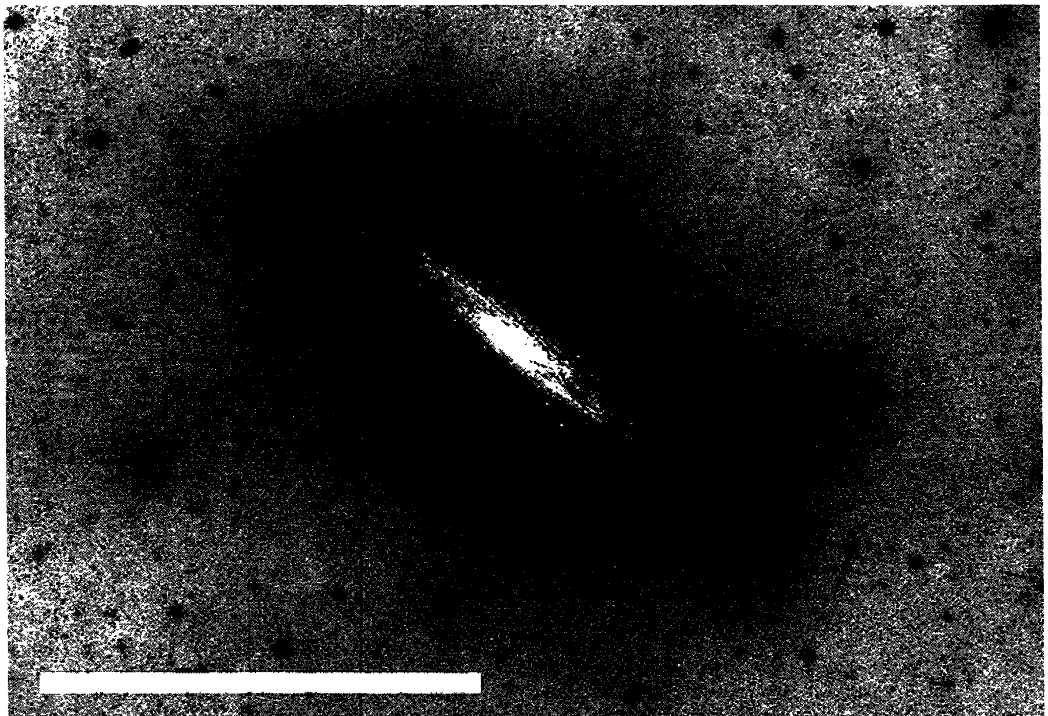

Fig. 4

Fig. 5

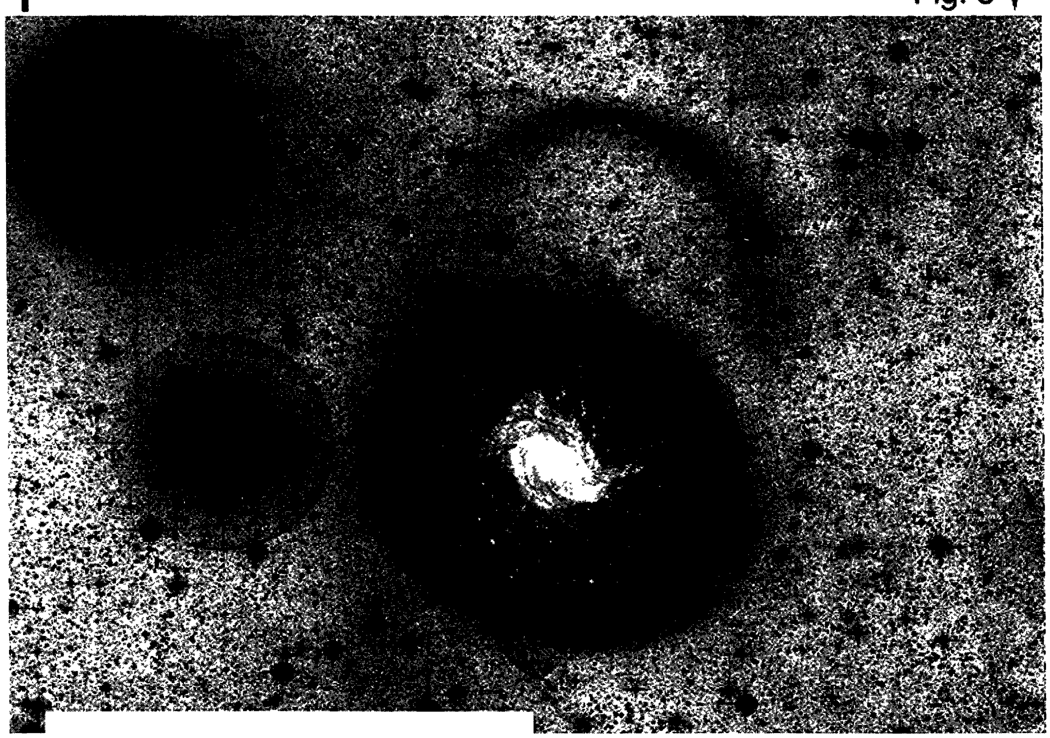

Figure 4—The extent of the faint outer envelope of NGC 253 is evident when compared to the normal contrast positive image, inset to the same scale. The scale bar is 30 arcmin.
Figure 5—Even well-known galaxies can spring surprises. This deep image of M83 reveals an enormous loop around the NW quadrant of the galaxy. The inset image is to the same scale as the main picture. The scale bar is 30 arcmin.

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Fig. 6

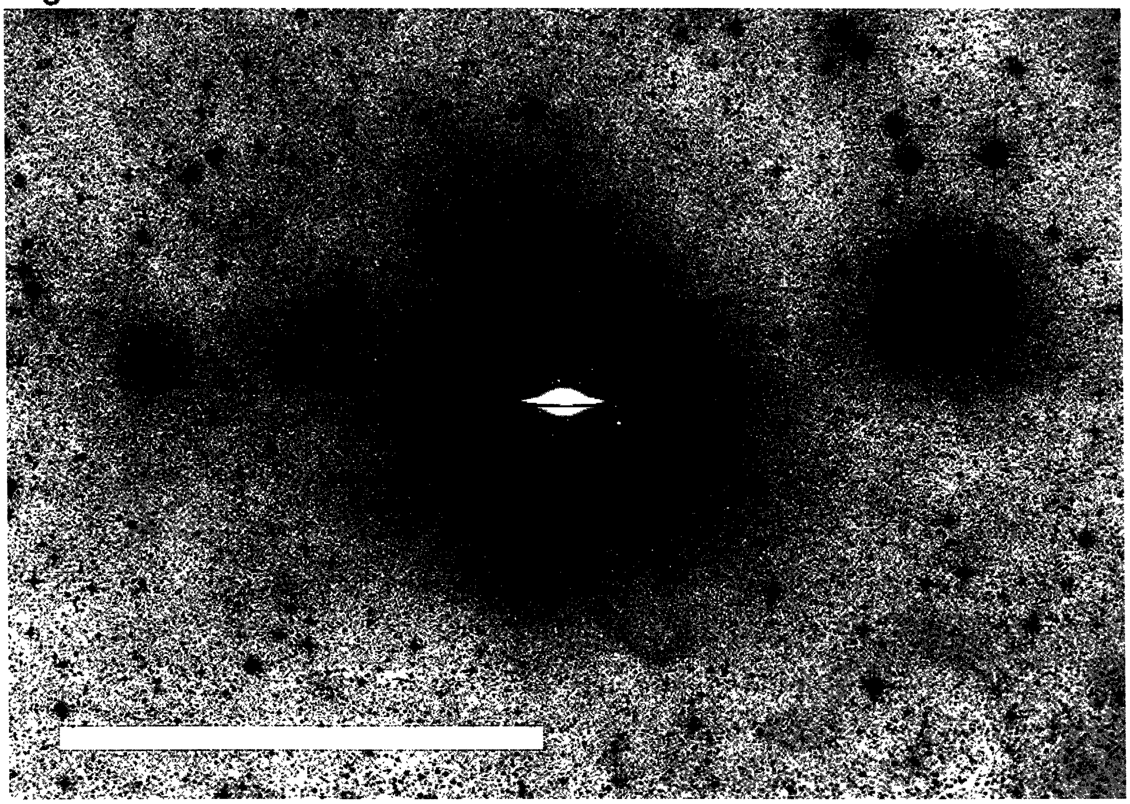

Fig. 7

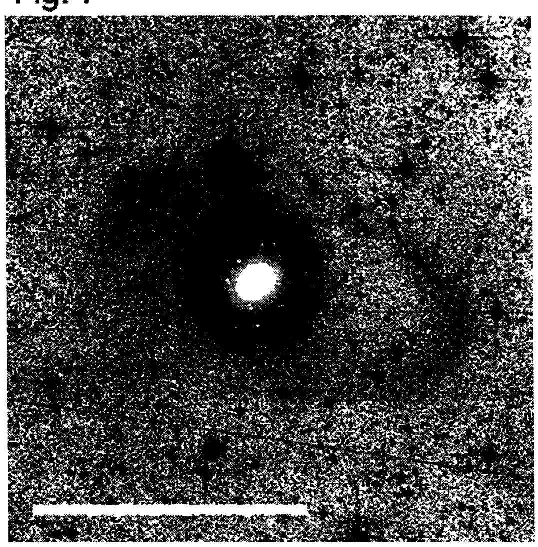

Figure 6—M104 looks like an E2 galaxy at low surface brightness. The outer 'elliptical' component is featureless except for a faint loop to the SSW and a corresponding faint feature without structure to the NNE. Scale bar is 30 arcmin.
Figure 7—NGC 2855 seems to be a perfectly ordinary SA(r) galaxy that has not previously attracted attention. However, its very extensive low surface brightness disk or ring suggests that the dynamics of this galaxy are unusual.

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greater than that of the neutral hydrogen envelope detected by Koribalski, Whiteoak & Houghton (1995), and it also extends well beyond the fields where Hawthorn has detected diffuse Hα emission (unpublished). Figure 4 is the result of combining the photographically amplified derivatives of five deep IIIa-J (i.e. blue–green) plates taken with the UK Schmidt Telescope. The image has a limiting surface brightness of about 28 mag arcsec^{-2} and shows that the low surface brightness envelope is devoid of fine detail and is unusual in not being strongly truncated, as is the case for most spirals. However, it also shows a distinct, asymmetrical extension in the southern half of the galaxy. This is difficult to understand, since NGC 253 is not obviously interacting with other members of the Sculptor group, and no other structures in the disk of the galaxy, or in the H I velocity profile, suggest any kind of external disturbance.

Preliminary calculations by Hawthorn (unpublished) show that neither line emission nor scattered light can account for the faint light in the 400–530 nm passband recorded here, so the most likely explanation is that we are seeing an extended, asymmetrical stellar halo, perhaps distorted by the infall of a companion galaxy which has long since been absorbed. However, it should be noted that the southern part of the galaxy, where the anomalous extension is most obvious, is also the region with the strongest polarisation at 1·4 GHz, and the 0·33 GHz diagram also shows a southern spur. Since NGC 253 is seen almost edge-on, the anomalous extension could be a line-of-sight loop or arc effectively detached from the main body of the galaxy, either the result of an ancient encounter, or, perhaps, the debris from the incomplete disruption or absorption of a Magellanic Cloud-like companion.

M83 (NGC 5236) is a spectacular face-on spiral galaxy. Colour photographs show it to have clumpy, well-defined spiral arms, evidently rich in young blue stars. The galaxy is remarkably symmetrical and has no obvious companions or evidence of interaction. However, deep images (Figure 5) reveal an extensive but very faint arcuate structure to the northwest of the galaxy, clearly centred on it, but completely disconnected from it. The arc has a maximum projected distance of about 55 kpc from the nucleus of M83 and is of a similar length, though this is very difficult to determine precisely. The structure was first noted some years ago by Cannon (private communication). It is apparently devoid of the fine detail typical of the extensive but faint Galactic reflection nebulosity which is detectable in the Centaurus–Hydra direction and is seen on many deep plates taken on different centres, so is certainly real.

The galaxy also has a very extensive H I halo with 80 per cent of the detected H I beyond the Holmberg radius, much more than is normal in such galaxies (Huchtmeier & Bohnenstengel 1981). A distinct ridge in the H I velocity profiles is seen in their data, at a position that corresponds to the optical loop, but extending well beyond it. If M83 were strongly inclined to the line of sight, it may well be that the faint loop would appear as an extension to one end of the galaxy, rather like that in NGC 253.

The well-known Sombrero galaxy, M104 (NGC 4594), shows no signs of interaction even on the deepest optical images, nor is there anything unusual in the H I distribution or velocity structure, and though the H I mass is unusually small, there is no evidence of large radial velocities (Bajaja et al. 1984). However, M104 shows an unexpected faint feature at a considerable projected distance to the SSW of the galaxy (position angle about 200 degrees). This takes the form of a faint loop (Figure 6) which appears to be associated with M104, but, like that in M83, is seemingly detached from it. The loop is at a projected distance of about 20 arcmin, extending 100 kpc from the nucleus if the distance to M104 is taken as 18·6 Mpc. The loop is sharp-edged and quite distinctive, but in the image reproduced as Figure 6 there is also a strong suggestion of a more diffuse faint structure of similar extent to the NNE of the galaxy, diametrically opposed to the loop at position angle 20 degrees.

There is no previous mention of this feature in the literature, and there is no evidence of these structures in the contours of M104 reproduced by Burkhead (1986). However, Burkhead's contours, which extend to 28 mag arcsec^{-2}, were red-light exposures aimed at tracing the extent of the red bulge of M104, while the image reproduced in Figure 6 was made on IIIa-J plates which would tend to emphasise blue features.

Our final example of a spiral galaxy with unexpected faint features is NGC 2855, an SA(r) galaxy remarkable for its ordinariness (Figure 7). It appears in many lists of galaxies in the literature but is not singled out as in any way notable. However, combined multiple exposures reveal an enormous, faint, almost complete loop or perhaps a disk seen in projection. Like most of the faint features noted here, it has a surface brightness fainter than 28 mag arcsec^{-2}. At this stage, that is all that can be said about it, but the enormous extent of this feature makes NGC 2855 worthy of further study.

4 Summary

In many of the examples mentioned above, optical peculiarities seem to be associated with anomalies in the H I distribution within and around galaxies that appear quite normal optically unless special image enhancement techniques are used. Some of

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these anomalies are clearly the result of interactions or perhaps the high-velocity encounters described as 'galaxy harassment' by Moore et al. (1996). However, it also seems that optical diagnosis is a more sensitive indicator of recent harassment than is H I observation, though the latter technique may reveal traces of earlier interactions that are no longer evident as optical anomalies.

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