OPTICAL POLARISATION STUDIES OF GALAXIES

S.M.SCARROTT, C.D.ROLPH & D.P.SEMPLE
Physics Department
University of Durham
Durham
DH1 3LE
UK

ABSTRACT. High spatial resolution maps of the optical linear polarisation of a range of galaxies of different morphological types and inclinations are presented. Spiral, barred spiral and irregular galaxies with low inclinations show spiral patterns of polarisation orientation which may be interpreted to indicate that there are large-scale magnetic fields present in the discs of these galaxies. A survey of edge-on galaxies with conspicuous equatorial dust lanes shows remarkable differences in polarisation structure between early and late types. In the Sa galaxies the polarisation in the dust lane is sizeable and parallel to the dust lanes, suggesting that the magnetic field is uniformly distributed in the plane of the galaxy. This polarisation pattern disappears in the Sc galaxies suggesting that the relatively chaotic dust features do not possess a grain aligning mechanism, e.g. a magnetic field, that is uniform or coherent over large distance scales. It is clear that most galaxies do have polarisation patterns that are related to galactic structure and inclination, and further similar polarisation studies should help to unravel the relationship between the generation of polarisation and galactic magnetism.

1. Introduction

Although the study of the configuration of magnetic fields in galaxies of various morphological types has been investigated by various means the predominant technique has involved the mapping of polarisation at radio wavelengths. The success of this approach can be judged by the number of contributions to this Symposium based on the analysis of such results.

Radio linear polarisation arises from the synchrotron process which links the orientation of the polarisation to the projected magnetic field direction. Although this process does not give rise to optical polarisation in normal galaxies there is a mechanism whereby selective extinction by magnetically aligned grains creates linear polarisation whose orientation is parallel to the projected magnetic field direction. Scarrott et al. (1986) discussed the possibilities of relating high resolution optical polarisation maps to galactic magnetic fields via the Davis-Greenstein effect but there are the additional difficulties of separating out the effects of other polarising mechanisms, particularly simple scattering of light by dust grains, which may also contribute to the polarisation in galaxies.

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2. Optical polarisation in the spiral galaxies M51 and NGC1068

Scarrott et al. (1986,1987) published the first high spatial resolution maps of the nearly face-on galaxies M51 and NGC1068. In each case the polarisation orientations followed a spiral pattern from close to the nucleus to the periphery of the galaxy. The orthogonality of the optical and 6-cm radio polarisations (Sergalowitz et al. 1976) at similar locations in M51 led to the proposal that optical polarisations were tracers of the magnetic field orientation in M51, implying that there is a large scale magnetic field in the disk of M51 and in other galaxies which show similar structure in the optical polarisation pattern.

3. Optical polarisation in galaxies with edge-on dust lanes

The copious extinction in the equatorial dust lanes of edge-on galaxies such as M104/NGC4594 and NGC5128 makes these objects prime candidates for observing polarisation in the light emanating from the dust regions. Both galaxies show polarisation within the dust lane with orientations parallel to the dust lane/plane of the galaxy which may be interpreted to show that there is a uniform magnetic field in the plane of the galaxy (Scarrott et al. 1977, Scarrott et al. 1986, Elvius & Hall 1964, Berry 1985).

However, Jura (1982) proposed a model whereby such polarisations in the dust lanes of galaxies such as M104 and NGC5128 could arise from the non-uniform illumination of the dust grains by the asymmetric distribution of stars within the galaxy, so that the origin of the polarisation was the scattering of light rather than selective extinction. More recently a similar scattering model (Matsamura and Seki 1989) was unable to predict the magnitudes or orientations of the observed polarisations in the dust lane of M104.

NGC5128 (Cen A, a peculiar elliptical galaxy) has a very prominent equatorial dust lane that shows quite uniform polarisations (typically 4-5%) parallel to the dust lane. The Monte-carlo scattering model of Berry (1985) was unable to account for the observed levels of polarisation and he proposed that a uniform toroidal magnetic field existed in the plane of the galaxy with selective extinction by magnetically aligned grains giving rise to the observed polarisation pattern. Fortuitously, in 1986 a supernova occurred within, or behind, the dust lane in NGC5128 and the detailed wavelength dependence of the linear polarisation of the SN indicated to Hough et al. (1987) that extinction by magnetically aligned grains was responsible for creating the observed $P(\lambda)$ curve. By fitting a Serkowski Law, the empirical law derived from observations of polarisations induced by magnetic effects in our Galaxy, to the SN data they were able to deduce that the dust grains in NGC5128 were smaller than those in this Galaxy. These observations provided irrefutable evidence that the polarisation in the dust lane of NGC5128 arose from magnetic effects rather than simple dust scattering. By analogy, other similar galaxies should show a similar behaviour in the $P(\lambda)$ curve.

In fig.1 we show a compilation of polarisation maps for edge-on galaxies of different morphological types. The most impressive pattern is for the Sa galaxy M104 with its striking equatorial dust lane. The polarisations, as in the case of NGC5128, are predominantly parallel to the dust lane in the central regions of the galaxy. We have measured the wavelength dependence of the polarisation in the central region of the dust lane and this is displayed in fig.2. The polarisation rises at shorter wavelengths

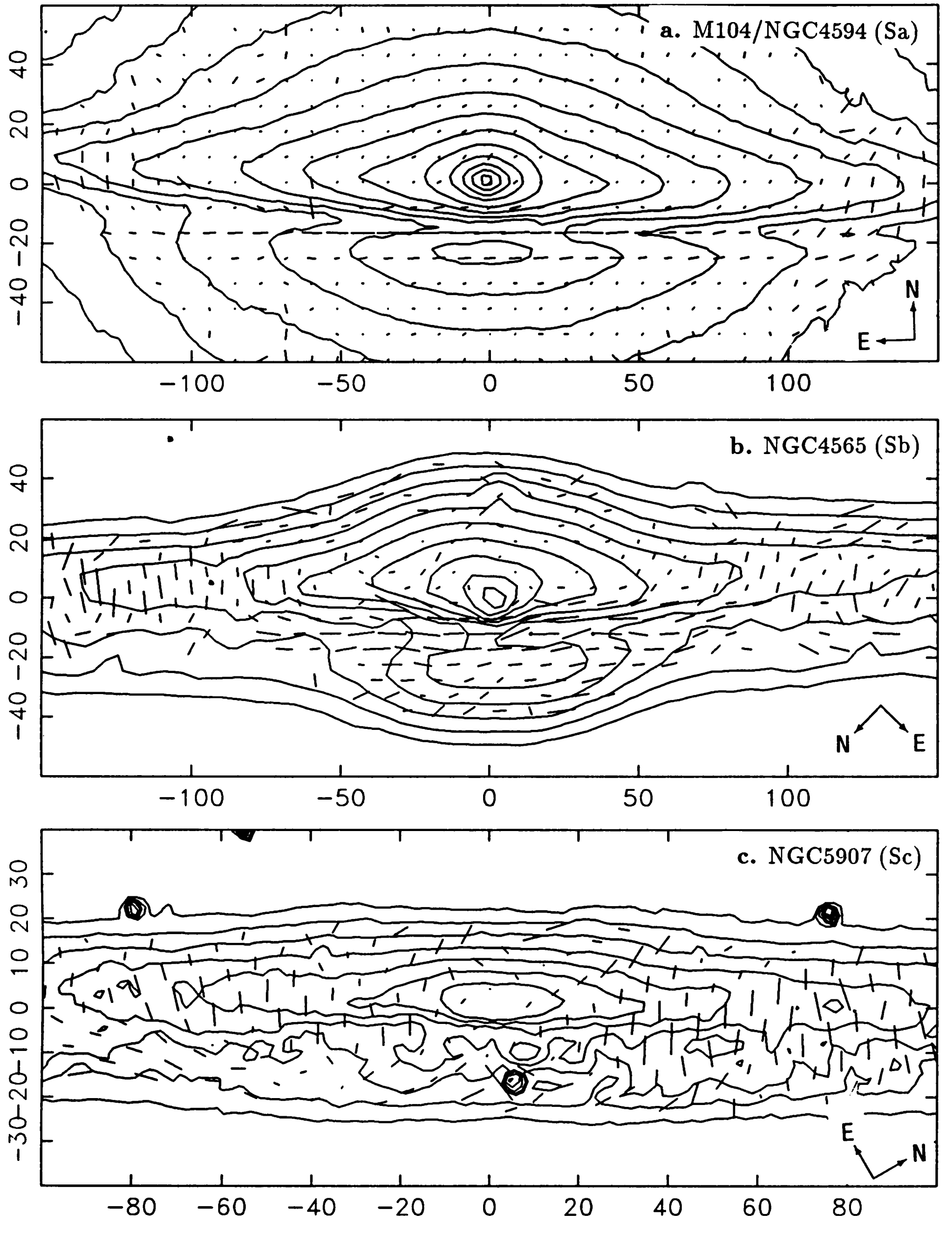

Figure 1. Polarisation maps of three nearly edge-on galaxies with dust lanes. Note that the polarisation parallel to the dust lane in the Sa galaxy gradually diminishes to zero levels for the later-type galaxy. The axes are labelled in arcseconds offset from the centre of each galaxy, and the contours are plotted at half-magnitude intervals.

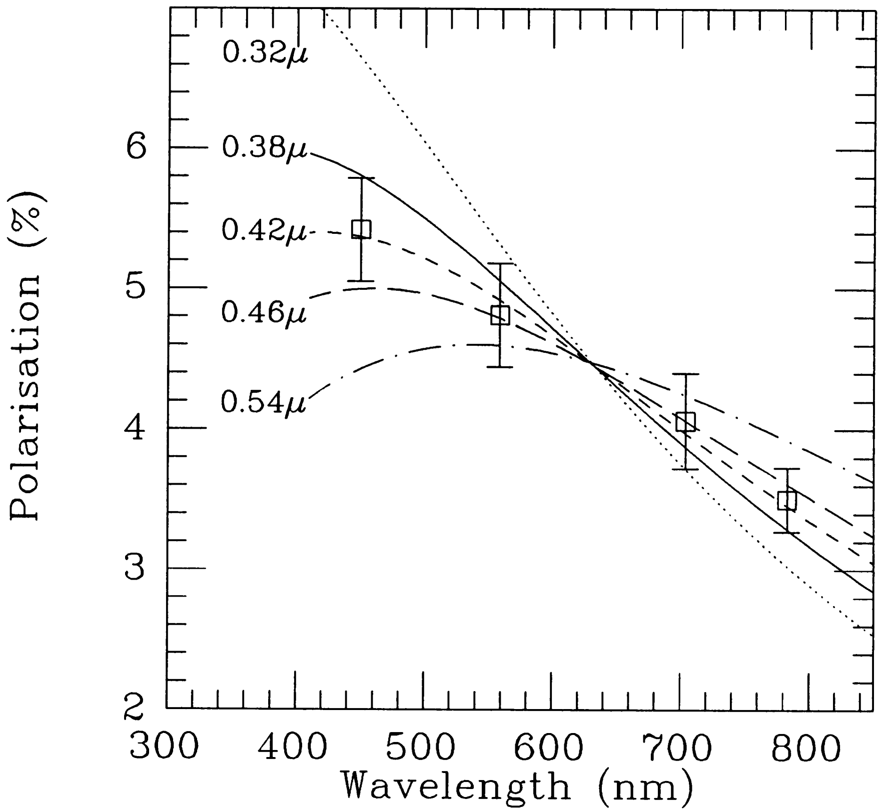

Figure 2. The wavelength dependence of the polarisation in the dust lane of M104. The curves represent fits to the data for the Serkowski law with different values of λ_{max}.

and the curves represent fits to the data for the Serkowski Law with different values of the variable λ_{max}, the wavelength of maximum polarisation. The optimum fit gives $\lambda_{max} \sim 0.42\mu$, a value very similar to that found by Hough et al. for NGC5128 (0.43μ), again implying smaller grains in M104 than in the Galaxy. The ability of the Serkowski Law to fit the wavelength dependence of polarisation in the dust lane of M104 gives further credence to the proposal that there is a toroidal magnetic field in this galaxy which aligns grains in the dust lane.

Although the pattern of polarisations is parallel to the dust lane in the central regions of the galaxy, at the extremities of the galaxy ($\sim 120''$ E/W of the nucleus), where the dust lane can be seen to go behind the galaxy, the polarisations change orientation and become perpendicular to the dust lane/plane of the galaxy. This behaviour may be interpreted in terms of scattering since in this location any illumination will be from the inner parts of the galaxy and such a one-sided distribution of illuminators would give rise to polarisations of the observed orientation. On the other hand if the magnetic field maintains the expected toroidal configuration then the small tilt of the galaxy to our line of sight will produce a net component of magnetic field perpendicular to the plane of the galaxy and selective extinction will also produce a pattern similar to the one observed.

Figs.1b & 1c show maps for two later type galaxies with equatorial dust lanes seen almost edge-on. NGC4565 (Sb) appears to have a regular dust lane in the central regions (150″ from the nucleus) and its intensity contour map is very similar to that of M104 except for the diminution of the galactic bulge as expected for a Sb galaxy. The central parts of the dust lane show relatively uniform polarisations parallel to the dust lane/plane of the galaxy but the level of polarisation is approximately half that observed in M104. Furthermore the polarisation parallel to the dust lane gradually peters out by 175″ from the nucleus and beyond this distance the polarisations become perpendicular to the dust lane and plane of the galaxy. The effect seen at the extremities of the equatorial plane in M104 now appears relatively close to the nuclear region in NGC4565.

NGC5907 (Sc) shows an irregular dust lane as befits its classification and we observe no measurable polarisation in the dust lane. On the other hand the polarisation perpendicular to the plane of the galaxy is now seen throughout the galaxy except within the nucleus itself. The level of this polarisation is quite small compared to that seen in the two earlier type galaxies. The polarisation data presented in a poster paper on NGC3079 by Neiniger et al. at this Symposium also exhibits a hint of the behaviour seen in NGC5907 as does some of our own unpublished data for NGC7331 and NGC6903.

There appears to be a correlation between polarisation pattern and morphological type for edge-on galaxies with dust lanes. To summarize -

1. Early type galaxies with uniform dust lanes have significant levels of polarisation (4-5%) parallel to the dust lane. Later galaxies have reducing levels of polarisation culminating with no measurable polarisation for an Sc galaxy.
2. The polarisations perpendicular to the dust lane/plane of the galaxy seen only at the extremities of the Sa galaxy gradually extend inward as later type galaxies are encountered until the whole of the Sc galaxy (excluding the nucleus itself) shows only perpendicular polarisations.

Feature 1 appears to be saying that the level of polarisation parallel to the dust lane depends on the uniformity of the dust lane; as the uniformity decreases then so does the polarisation. This implies that the polarising mechanism giving rise to such polarisations appears to be associated with the uniformity of the dust lane which, in turn, indicates that it is related to galactic structure. If selective extinction is the operative mechanism then it seems that either the field strength or its uniformity along our line of sight within the galaxy is decreasing for later type galaxies. If the mechanism is simple scattering then this must depend on the relative distributions of illuminators in the various galaxies. It is difficult to see how the disappearance of polarisation in the dust lane of the Sc galaxy can be attributed to the effects of illumination.

The gradual appearance of feature 2 as we progress to later galaxy types is probably due to the disappearance of the galactic bulge which swamps the effect for early type galaxies except at the very extremities of these galaxies. If this polarisation feature is due to selective extinction then we are sampling the vertical component of the planar field resulting from the slight tilt of these galaxies. This would give highest polarisation along the long axis of the galaxy where the projected line of sight is maximum. If scattering is the dominant polarising mechanism producing this effect it is difficult to see how the polarisation disappears in the chaotic foreground dust lane for Sc galaxies.

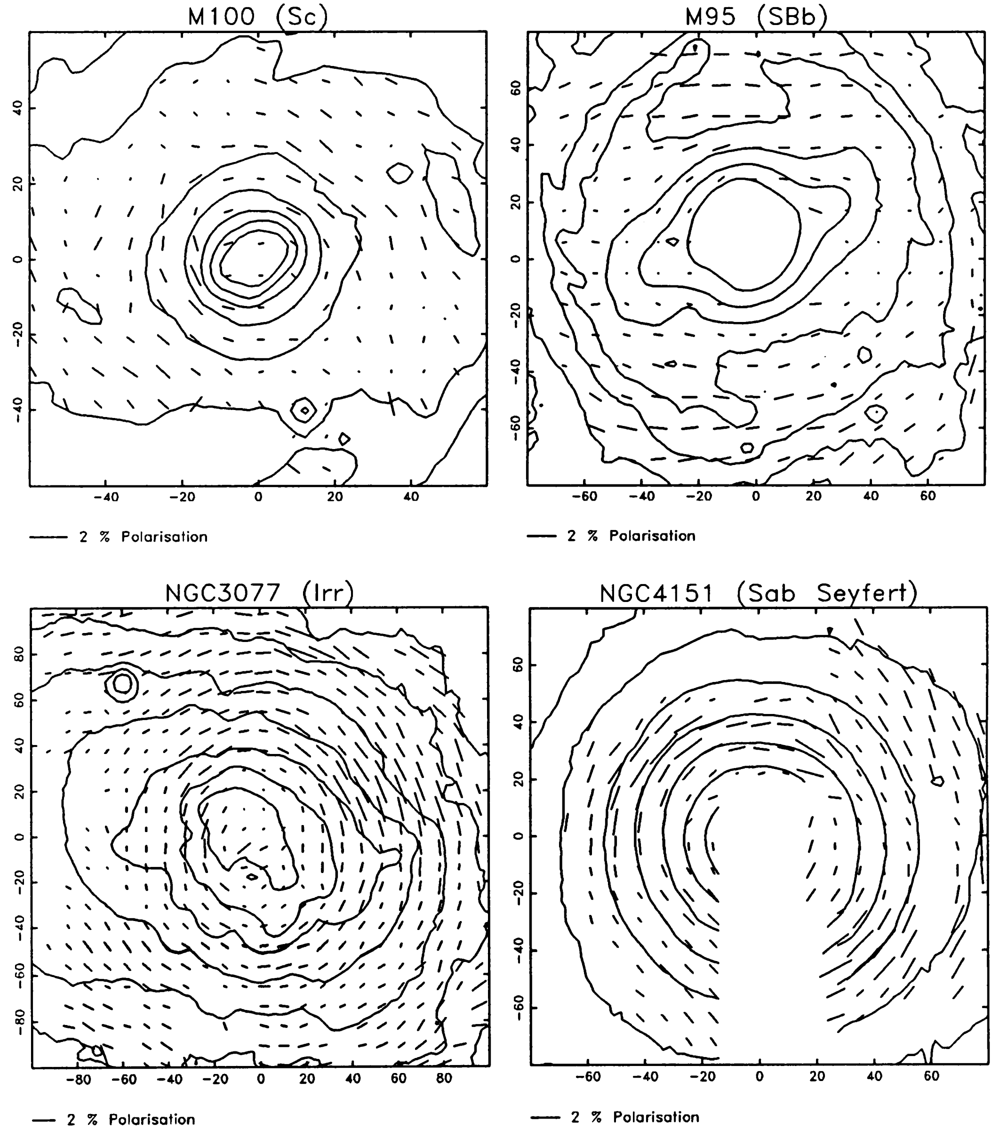

Figure 3. The polarisation maps of a selection of galaxies of varying morphological type. The axes are labelled in arcseconds offset from the centre of each galaxy.

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4. Optical polarisation in other galaxies

We have looked at a selection of galaxies of other morphologies and inclinations and these are displayed in fig. 3. The results are summarized as follows.

M100, a face-on Sc galaxy has very little polarisation in the outer parts but the inner 30″ shows a spiral pattern of polarisation orientations.

M95, a barred spiral (SBb) seen almost face-on, shows no polarisation within the bar but there is a pattern of polarisation sweeping out parallel to the spiral arms from the ends of the bar.

NGC3077, a small irregular galaxy associated with the M81/82 group, also show a significant polarisation pattern in the form of a spiral emanating from the near nuclear region.

Finally, the well-known Seyfert galaxy NGC4151 has a near-circular pattern in the non-nuclear regions.

5. Conclusion

Careful mapping of the optical linear polarisation in a range of galaxies of different morphological types and inclinations reveal general trends in polarisation patterns. Spirals, barred spirals and even an irregular galaxy when seen nearly face-on show polarisation patterns that follow a spiral pattern. If these polarisations arise from selective extinction by magnetically aligned grains then this implies that the galactic magnetic fields also follow the spiral arms in a large scale configuration.

Early type edge-on galaxies show polarisation parallel to the equatorial dust lanes but this feature diminishes for later type galaxies where there is no observable polarisation in the relatively chaotic dust lane. Conversely, the later type galaxies show polarisation perpendicular to the plane of the galaxy throughout the galaxy. These results again may be interpreted in terms of a large scale magnetic field in the plane of these galaxies.

Almost all galaxies show optical polarisation in patterns that seem to be linked to the structure, morphological type and inclination of the objects. The interpretation of the data may suggest the presence of planar fields in galaxies but further investigations, especially in terms of the wavelength dependence of polarisation, are required to confirm that the dominant polarising mechanism in galaxies is selective extinction rather than scattering.

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