Further evidence for vertical magnetic fields in the galaxy NGC 891

S. M. Scarrott and P. W. Draper

Physics Department, University of Durham, South Road, Durham DH1 3LE

Accepted 1995 August 14. Received 1995 August 2; in original form 1995 July 12

ABSTRACT

An optical polarization map of NGC 891, an edge-on galaxy with similar properties to the Galaxy, confirms that there are vertical magnetic fields present in the bulge/halo above the inner part of the galactic disc. We find no evidence for large-scale magnetic fields in the central dust lane, or polarization created by scattering from dust grains within the dust lane and elsewhere in the galaxy.

Key words: polarization – galaxies: individual: NGC 891 – galaxies: magnetic fields – galaxies: spiral.

1 INTRODUCTION

NGC 891 is a nearby galaxy, classified as Sbc, and seen almost edge-on with an extensive and irregular central dust lane. NGC 891 has many similarities with the Galaxy, and this has prompted many investigations which lead indirectly toward information regarding our own system, particularly the Galactic halo. NGC 891 has an extensive halo which has been mapped, inter alia, in radio continuum, diffuse ionized gas, molecular gas and X-ray emission, and many of these features appear to be interlinked and point towards a rather active halo powered by winds and outflows originating in star-forming regions distributed in the inner 9 kpc of the galactic disc (Hummel et al. 1991; Keppel et al. 1991; García-Burillo et al. 1992; Bregman & Plidis 1994; Dahlem, Dettmar & Hummel 1994).

One of the more intriguing features of the halo of NGC 891 is that the polarization of the radio continuum distribution indicates that the magnetic field lines are vertical, i.e. perpendicular to the plane of the disc of the galaxy (Sukumar & Allen 1991, and references therein). The origin of this field geometry has prompted considerable interest, since the conventional dynamo processes used to explain the generation of galactic magnetic fields lead to azimuthal configurations in the plane of the galaxy. There have been several proposals for generating vertical halo fields (Kronberg 1994 gives a comprehensive review of extragalactic magnetic fields including those in galactic haloes), and the general moves have been either to attribute the halo field to energetic (starburst) outflows alone, or to couple less energetic outflows into the traditional dynamo models which account for the azimuthal configuration in the disc itself. It is clear that there is more than one origin for halo fields: Lesch & Harnett (1993) and Chiba & Lesch (1994) argue that supernovae-driven winds create the halo field in M82, large-scale galactic winds produce the same effect in NGC 4631, while locally enhanced star formation throughout the inner disc provides the impetus to redirect the azimuthal disc field into the vertical configuration observed in the bulge/halo of NGC 891.

Radio continuum polarization measurements provide a reliable way of mapping magnetic fields in galaxies, but they are subject to the effects of Faraday rotation and limited spatial resolution. In the optical regime, polarization induced by dichroism by magnetically aligned grains has been observed in galaxies, and this provides another means of mapping the fields (e.g., the Galaxy – Mathewson & Ford 1970; M51 – Scarrott, Ward-Thompson & Warren-Smith 1987; M104 – Scarrott, Rolph & Semple 1990); however, with the optical observations it is sometimes difficult to rule out contributions to the polarization from simple scattering.

In the present paper, we show a V-wavelength polarization map of the galaxy NGC 891 which provides further evidence for vertical magnetic fields in this object. The origin of the optical polarization is discussed.

2 OBSERVATIONAL DETAILS

NGC 891 was observed using the ING 1.0-m JKT on La Palma together with the Durham Imaging CCD Polarimeter (Scarrott et al. 1983; Scarrott 1991) during 1992 November. Observations were made using a V-wavelength filter; seven fields, each comprising four CCD images (half-waveplate positions of 22.5°, 45°, 67.5° and 90°), were taken, giving a total exposure of 14400 s. The data were reduced in our standard manner (Draper 1988) to yield the results described later.

The field stars in each of the CCD frames were used to mutually align all the images to better than 0.25 arcsec. We
took a bright field star seen against the central dust lane as the origin of our coordinate system data so that it can be readily identified on other optical images. Sukumar & Allen (1991) give the positions of several fields stars in the NGC 891 region which they used for astrometric purposes in their radio observations. We have used these positions to give an absolute calibration (to $\approx 3$ arcsec) for our polarimetric data. NGC 891 is at a distance of 9.5 Mpc, which gives a scale $\approx 45$ pc arcsec$^{-1}$, assuming $H_0=75$ km s$^{-1}$ Mpc$^{-1}$ (Garcia-Burillo et al. 1992).

3 RESULTS AND DISCUSSION

3.1 Features of the polarization maps

The data are shown in a sequence of polarization maps which illustrate the results at various spatial resolutions. In the large-scale map shown in Fig. 1 (left) the polarization is measured in integration bins of 12-arcsec diameter on an array of centres regularly spaced at intervals of 12 arcsec in RA and Dec. Within the central bright bulge/halo (centrogalactic distances $\approx \pm 4.5$ kpc) the polarization is oriented approximately perpendicular to the disc/galactic plane. To the south of this region we see no significant polarization pattern, whereas to the north any measured polarization tends to run parallel to the disc. In this figure it is difficult to discern any polarization in the dust lane, due to the fact that in many instances the integration bin sizes exceed the width of the lane. We have selected the positions of several of the small clumps of obscuration in the rather irregular dust lane, and measured the polarization at each of these centres using a simulated circular aperture of 5 arcsec. These measurements are shown in Fig. 1 (right), and it is seen that, although we find polarization levels up to about 2 per cent locally, there is no uniform pattern of vector orientations on kpc scales as found in other dust-lane galaxies such as M104 and NGC 5128.

In Fig. 2 we show the central bulge/halo region at a higher spatial resolution. The right-hand frame shows the dust-lane polarizations at the selected positions described earlier, and even in the central regions there is no coherent pattern of vector orientations. The left-hand frame shows that the bulge/inner halo on either side of the dust lane is polarized at levels of $\approx 1$ per cent, with the vectors oriented

Figure 1. Polarization data for the galaxy NGC 891. Left: a large-scale polarization map of the whole of the galaxy. Right: polarization measurements for the more obscured regions of the central dust lane. The star used as the centre of the coordinate system is at RA(1950)=$02^{h} 19^{m} 25^{s} 0$, Dec.(1950)=$42^{o} 07^{'} 32^{''} 0$. 

© 1996 RAS, MNRAS 278, 519–524

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System
Vertical magnetic fields in the galaxy NGC 891

Figure 2. As Fig. 1, but for the central \( \pm 4.5 \) kpc of the galaxy. Note that the polarization orientations in the bulge/halo regions are perpendicular to the plane of the galaxy.

approximately perpendicular to the disc. There is a hint of deviations from perpendicularity, and these are better discerned in Fig. 3 where we give a map of the inner \( \pm 1.3 \) kpc and plot the length of the vectors proportional to the measured polarized intensity at any point rather than the level of polarization. Although in many locations the vectors are close to perpendicular to the plane of the disc as defined by the dust lane (we do not fail to appreciate that measurement errors also produce fluctuations in vector orientations), there appear to be local subpatterns, the most significant of which occurs in both the E and W bulges at about 3 arcsec north-north-east of the centre of our coordinate system.

3.2 General discussion

It is evident from the previous section that there is widespread polarization in the central regions of NGC 891, but its origins may not be readily attributed in a global sense to a particular polarizing mechanism. In the circumstances we will consider the polarization in the dust lane and bulges as separate issues, before attempting to come to a general consensus.

3.2.1 The effects of interstellar polarization in the Galaxy

The galactic coordinates of NGC 891 are \( l=140^\circ \) and \( b=-17^\circ \), and the proximity of the line of sight to NGC 891 to our own Galactic plane might lead to polarization in the light from NGC 891 induced in our own Galaxy by magnetic dichroism. It so happens that the galactic planes of NGC 891 and our Galaxy are almost orthogonal so that any locally produced polarization would be perpendicular to the dust lane in NGC 891 (the stellar polarizations in our Galaxy at \( l=140^\circ \) and \(-10^\circ \leq b \leq 10^\circ \) are strongly ordered parallel to our Galactic plane - Mathewson & Ford 1970).

We have measured the polarization of the stars (i.e. local to the Galaxy) in the field of NGC 891, and find no significant polarization with orientation parallel to that observed in NGC 891. There is also a small galaxy (offset 75 arcsec east, 100 arcsec north) in the field which does not show any polarization, and we believe that these field measurements (stars and distant galaxy) coupled with the lack of polarization in the dust lane tend to eliminate the possibility that the polarization elsewhere in NGC 891 is created locally in our Galaxy.
3.2.2 Polarization in the dust lane

Edge-on galaxies with well-defined and regular dust lanes are usually found to be polarized in the central parts of the dust lanes (typically 4 per cent), with the polarization vectors oriented parallel to the dust lane (M104 – Scarrott et al. 1990; NGC 5128 – Berry 1985; Hough et al. 1987; IC 4329A – Wolstencroft et al. 1995). These authors have attributed this polarization to the effects of dichroic extinction by magnetically aligned grains, implying that the magnetic fields, within the equatorial plane of these galaxies, are uniform on kpc scalelengths. There are at least two other compelling pieces of evidence which suggest that dichroism is present in dust-lane galaxies: Hough et al. (1987) found that the polarization orientation for the supernova SN 1987G, located within the dust lane of NGC 5128, was similar to that in the remainder of the dust lane and, similarly, Wolstencroft et al. (1995) observed that the polarization orientation of the central AGN, seen behind the dust lane in IC 4329A, was parallel to that seen elsewhere in the dust lane.

Conversely, this polarization has also been ascribed to scattering in an (optically thin) dust lane with an anisotropic illuminating geometry provided by the distribution of stars in edge-on galaxies (e.g., M104 – Jura 1982; Matsamura & Seki 1989). If scattering is the dominant process giving rise to dust-lane polarizations, then realistic scattering models will have to be developed to account for the levels and orientations of polarization in these galaxies.
We do not find any large-scale polarization pattern in the dust lane of NGC 891, either in the central regions, or beyond. The dust lane in NGC 891 appears to be fragmented, and the advocates of dichroism would claim either that there is no magnetic field uniform on kpc scales, at least in the very outer regions where we see the clumpy obscuration, or that the grain alignment has been suppressed in some manner (e.g., by local turbulent motions). However, our results do not exclude the possibilities that there are randomly oriented fields in the localized clumps, or that there is a uniform azimuthal/toroidal field in the inner parts of the plane of the galaxy into which we cannot see at optical wavelengths.

It is not unreasonable to have a dust lane without a large-scale magnetic field and/or grain alignment, but it is more difficult to imagine that we can have a dust lane without scattering since this polarizing process depends only on the presence of dust and anisotropic illumination. However, if the dust is optically thick, then multiple scattering will occur, and this has the effect of reducing the efficacy of the anisotropy of the illumination and also limits the level of polarization. Our observation of the lack of coherently oriented polarization in the dust lane in NGC 891 suggests that an anisotropic scattering process is not capable of generating measurable polarization in this (and other) galaxies with optically thick dust lanes.

3.2.3 Polarization in the central bulge/halo

The polarization throughout the central bulge/halo (galactocentric distances \( \pm 4.5 \) kpc) is generally perpendicular to the plane of the galaxy. How do we account for this polarization? Any dust on the north and south peripheries of the bulge will be illuminated predominantly from the inner parts of the bulge and the criteria of the anisotropic scattering hypothesis will be met; we could therefore expect polarization with the observed orientation. However, there is no anisotropy in the very central regions, yet even there the polarization shares the same orientation and pattern as elsewhere in the bulge/halo. It is difficult to account for this widespread and coherent pattern of polarization orientations in all these regions by scattering with an anisotropic illuminating geometry.

As described earlier, the halo of NGC 891 is relatively active in terms of X-ray, diffuse line and radio emission and possesses a vertical magnetic field, aspects which are all indicative of outflows fuelled by bounts of star formation spread throughout the inner 9 kpc of the disc. We will therefore attempt to account for the optical polarization in terms of these features. We associate the polarization with dust presently located in the bulge/halo region but probably originating in the star-forming regions in the disc itself and transported outwards in the flows known to propagate into the halo. In the previous paragraph we discounted the possibility that scattering from this dust gives rise to the observed polarization, so the only other really viable polarizing process is dichroism by aligned grains. We know from radio observations that there are vertical magnetic fields in NGC 891, so it is very tempting to assume that these align the grains by the same mechanism (the Davis–Greenstein effect) giving rise to the stellar polarizations observed in the Galaxy (Davis & Greenstein 1951; Mathewson & Ford 1970). Although this interpretation has initial attractions, there are drawbacks: in the Galaxy the non-spherical paramagnetic grains align in the azimuthal field within the disc on time-scales of \( \approx 10^7 \) yr, and in the more active environment of the bulge/halo of NGC 891 it is unlikely that the grains have sufficient time to align, especially in the presence of a net outflow from the disc of the galaxy. There have been several ideas to 'speed up' the alignment process (e.g., pinwheels, rockets, etc.), and Dolginov (1990) proposed that the basic Davis–Greenstein process of paramagnetic relaxation could be considerably accelerated (by an order of magnitude or more) in the presence of anisotropic gaseous flows. In NGC 891 we have the field and gaseous outflow situation, so that it may well be that the Dolginov mechanism is operative and gives rise to the observed polarization. Regardless of the precise details of the magnetic alignment mechanism, it appears that the optical polarization confirms the presence of a vertical magnetic field in the central bulge/halo region of NGC 891.

3.2.4 A Galactic Spur in NGC 891?

The seminal map of stellar polarizations in our Galaxy (Mathewson & Ford 1970) indicated that the majority of stars close to the Galactic Plane were polarized with E-vectors parallel to the plane; this led to the realization that the Galaxy possessed a relatively uniform azimuthal field in its disc. However, at \( l \approx 30° \) the polarizations are orientated perpendicular to plane for \( 20° \leq b \leq 50° \), and this feature is known as the North Galactic Spur and is attributed to the expanding envelope of a nearby \( (\leq 200 \) pc) supernova remnant.

In NGC 891 we see small-scale patterns \( (\approx 800 \) pc in dimension) in the polarization pattern; the one centred at 3 arcsec north-north-east of the centre of our coordinate system in Fig. 3 is the most conspicuous. We leave it open to conjecture as to whether these features are similar to our North Galactic Spur and result from recent and localized bursts of star formation in the disc of NGC 891.

3.2.5 Vertical magnetic fields in M82, NGC 4631 and our Galaxy

It is of interest to consider the optical polarization in two other galaxies which are known to have vertical halo fields (M82 – Reuter et al. 1994; NGC 4631 – Golla & Hummel 1994).

M82 is well known for a polarized halo in both optical continuum and emission-line wavebands, but the pattern of vectors is attributed unambiguously to the scattering of light from the central starburst and galactic disc by the halo dust. It is unlikely that we will be able to detect any polarization resulting from dichroism in the halo of M82, due to the presence of the overwhelming influence of the scattered light.

On the other hand, NGC 4631 is rather unusual in that we have not been able to detect any significant polarization in the halo, although this galaxy has extensive galactic winds which drive the vertical field and would be expected to transport dusty material outwards from the active central regions. The lack of any polarization from scattering in the halo indicates an absence of dust in these regions; this sug-
gests that the galactic winds have not carried significant amounts of dust into these areas—perhaps an indication of ‘starburst youth’ in which the faster outflows (UV radiation and ionizing winds) have reached the halo but the dust, created in the latter stages of starburst activity, has yet to arrive there.

In many ways the galaxy NGC 891 is similar to our Galaxy, and this implies that there should be a vertical magnetic field here also; there is, however, little evidence for such a feature. The North Galactic Spur, found in the optical data of Mathewson & Ford (1970), is believed to result from the galactic magnetic field being driven out into the halo by star formation/supernova activity, but this is a relatively local effect and cannot be compared with the situation in NGC 891 where activity throughout the inner disc is giving rise to the extended vertical fields. If there is such a field in our Galaxy, we may not have detected it in optical polarization measurements for the simple reason that most of the stars for which polarization data are available are within a few kpc of the Sun, so that any polarization would be due predominantly to the field in the disc rather than in the halo. A vertical field might be detectable in polarization observations of distant globular clusters (or galaxies for that matter) seen slightly above or below the Galactic plane in directions towards the centre of the Galaxy which would give long lines of sight through which the vertical field could exert its polarizing influence.

ACKNOWLEDGMENTS

The use of the facilities at the LPO is acknowledged. PPARC is thanked for its continuing financial support for the Durham polarimetry group.

REFERENCES

Kronberg P. P., 1994, Reports in Progress of Physics, 57, 325
Scarrott S. M., 1991, Vistas Astron., 34, 163

© 1996 RAS, MNRS 278, 519–524

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System