

Polarimetry of External Galaxies

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Abstract. This review presents results to date on the wavelength dependence of interstellar polarization (ISP) in other galaxies. A number of different techniques are discussed, and galaxy types range from those similar to the Milky Way Galaxy through to high-redshift radio galaxies. Although data are both sparse and generally limited in wavelength coverage, it appears that the ISP curves are similar to those in the Galaxy, indicating that the properties of dust grains responsible for producing the ISP vary little between different galaxy types. The advantages of using radio polarization maps to determine the magnetic field structure in galaxies is emphasized.

1. Introduction

Despite its importance, surprisingly few observations have been made of optical and infrared interstellar polarization (ISP) in other galaxies. Such observations can provide a measure of the dust size and dust optical properties (see the review by Whittet 1996): they are clearly important as probes of the nature and behavior of dust grains in different galactic environments, which can then provide a better understanding of the origin and evolution of dust in our Galaxy. Knowing the ISP in galaxies is important when studying the polarization properties of embedded sources, such as active galactic nuclei. In addition, polarimetry at optical, infrared and radio wavelengths can give direct information on the structure of galactic magnetic fields and, somewhat less directly, on the strength of the magnetic field.

This review will cover, for different galaxy types, aperture polarimetry of discrete light sources and of integrated starlight, imaging polarimetry at optical, infrared and radio wavelengths, and optical spectropolarimetry.

2. Aperture Polarimetry

2.1. Discrete Light Sources

While the polarization of external galaxies can always be measured, what contributes to it is often far from clear. The ISP can only be unambiguously determined if a dominant beacon of light is viewed through a dust column. Unfortunately there are few such observations, particularly with the good wavelength coverage needed to define the ISP curve adequately. This is especially impor-

Table 1. Summary of polarization observations of discrete sources in external galaxies.

Reference	Galaxy (type) Observation Discrete source	Principal results
Martin & Shawl (1979)	M31 (Sb) Optical $p(\lambda)$ Glob. cluster S78	$p(\lambda)$ Serkowski-like $\lambda_{\max} = 0.43 \pm 0.06 \mu\text{m}$ ($R_V \approx 2.5$ from colors) $p_{\max}/E_{B-V} = (10 \pm 1)\%/mag$
Clayton et al. (1983)	LMC (Irr) Optical $p(\lambda)$ 18 stars	$p(\lambda)$ Serkowski-like $\lambda_{\max} = 0.50\text{--}0.65 \mu\text{m}$ $\langle \lambda_{\max} \rangle \approx 0.58 \mu\text{m}$ ($R_V \approx 3.1$ from colors) p_{\max}/E_{B-V} typical of Galaxy but a few exceed 9%/mag
Hough et al. (1987)	NGC 5128 (Cen A) Optical-NIR $p(\lambda)$ Supernova 1986G	$p(\lambda)$ Serkowski-like $\lambda_{\max} = (0.43 \pm 0.01) \mu\text{m}$ θ parallel to dust lane $p_{\max}/E_{B-V} \approx 3.3\%/mag$
Magalhães et al. (1989)	SMC (Irr) Optical $p(\lambda)$ 3 stars	$p(\lambda)$ not well defined $p_{\max}/E_{B-V} < 9\%/mag$

tant in determining λ_{\max} , the wavelength of maximum polarization, which is a measure of the size of grains producing the polarization. Surprisingly, little advantage seems to have been taken in recent years of the power of larger telescopes on excellent sites with good image quality, and with optical and near-infrared detectors of high quantum efficiency, to measure discrete sources. More usually, it is integrated starlight which is observed and this will contain both scattered and transmitted components, often from different geometrical depths. The situation is then complex (see §2.2).

Table 1 summarizes observations to date of discrete sources where some wavelength coverage is available, allowing p_{\max} and/or λ_{\max} to be determined.

Clayton, Martin & Thompson (1983) observed 18 stars, mostly B type supergiants, in the Large Magellanic Cloud (LMC) at a minimum of three wavelength bands between $0.36 \mu\text{m}$ and $0.84 \mu\text{m}$. The filter passbands were selected to eliminate much of the nebular line emission seen around many of these stars. Stars with emission line spectra, or known to be variable were excluded. Spatial coverage was relatively poor as most stars with significant polarization are close to the 30 Dor region. In most cases, the degree of polarization as a function of wavelength, $p(\lambda)$, was consistent with a Serkowski curve (Serkowski

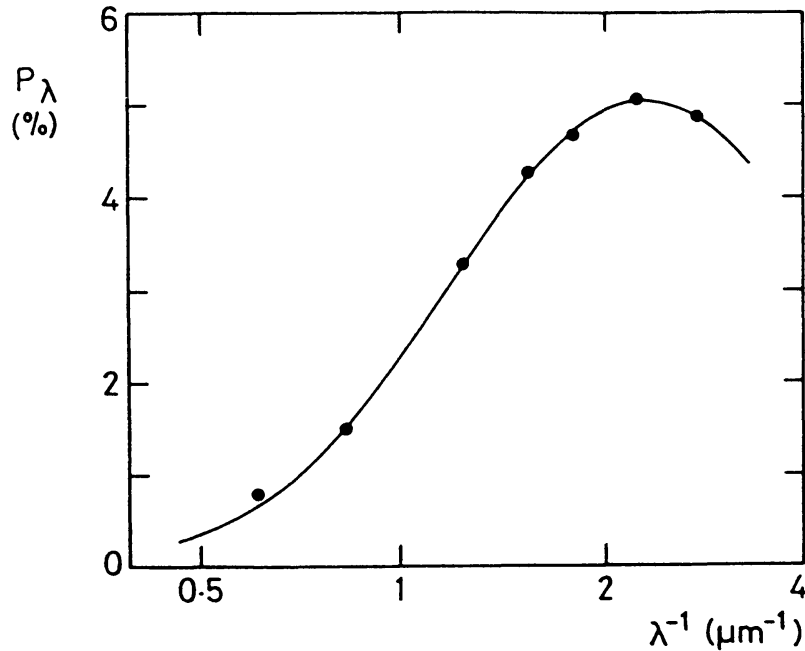


Figure 1. Wavelength dependence of polarization for SN1986G in Centaurus A (NGC 5128), taken from Hough et al. (1987). Solid circles: observations; curve: Serkowski fit.

1973, Serkowski, Mathewson & Ford 1975), with λ_{max} ranging from $0.50 \mu\text{m}$ to $0.65 \mu\text{m}$, and with an average value of $0.58 \mu\text{m}$, close to the average for the Galaxy of $0.55 \mu\text{m}$. The ratio of p_{max} to E_{B-V} is typical of Galactic values, although a few stars exceeded the maximum of $9\%/mag$ seen in the Galaxy, most likely due to incorrect classification of spectral types or intrinsic colors. Infrared observations of a number of the sample stars by Koornneef (1981) and Morgan & Nandy (1982) were used to show that the value of $R_V = A_V/E_{B-V}$ (the ratio of total to selective extinction) is within 10% of the average Galactic value of 3.1, which supports the Galactic relationship $R_V \approx 5.6 < \lambda_{\text{max}} >$.

Magalhães et al. (1989) measured three stars in the Small Magellanic Cloud (SMC) at five wavelengths between $0.4 \mu\text{m}$ and $0.8 \mu\text{m}$. Corrections for Galactic ISP are small, but the observed degrees of polarization are also quite small, making it difficult to define the $p(\lambda)$ curve, and thus only p_{max} is reasonably well determined. The ratios of p_{max} to E_{B-V} are typical of Galactic values, with none exceeding the maximum value of $9\%/mag$ seen in the Galaxy. Rodriguez, Coyne & Magalhães (1996) present further optical multicolor polarimetry of stars in the SMC, showing that λ_{max} is generally lower than the Galactic average.

Martin & Shawl (1979) determined the polarization of the globular cluster S78 in M31 (type Sb), at five optical wavelengths covering the wavelength range $0.37 \mu\text{m}$ to $0.81 \mu\text{m}$. Values of p_{max} and λ_{max} were calculated to be $(2.0 \pm 0.2)\%$ and $(0.43 \pm 0.06) \mu\text{m}$, respectively, results which were not thought to be sensitive

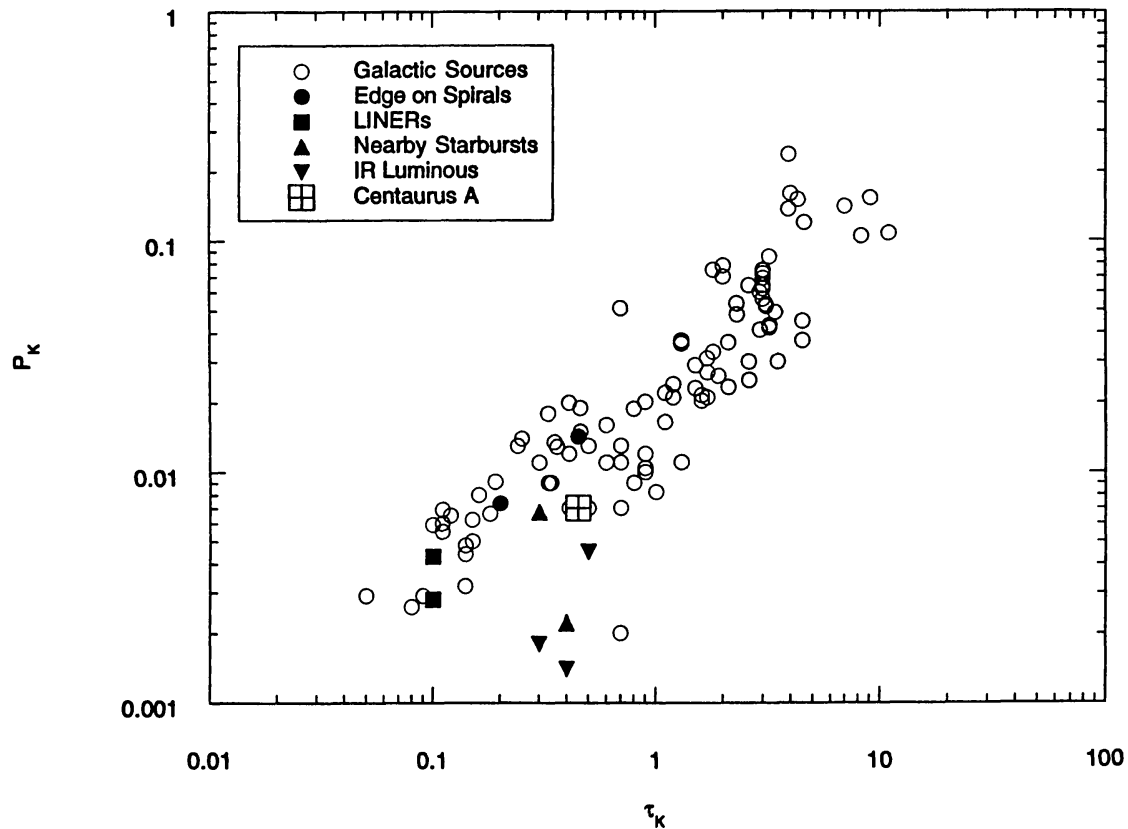


Figure 2. Polarization p_K plotted against optical depth τ_K for Galactic sources (from Jones 1989a) and a number of external galaxies. The latter are taken from Jones et al. (1990), with the exception of SN1986G in Cen A, which is from Hough et al. (1987).

to contributions from the Galactic ISP. The position angle of polarization is parallel to the galaxy long axis. The low value of λ_{\max} suggests that the grains along the line of sight to S78 are approximately 20% smaller than the average Galactic value (assuming similar grain types), consistent with the low value of R_V (2.5 ± 0.14) determined from the colors of S78 ($R_V/\lambda_{\max} = 5.8 \pm 1.1$). The value of the ratio p_{\max}/E_{B-V} is $(10 \pm 1)\%/mag$, somewhat higher than the maximum of $9\%/mag$ seen in the Galaxy, although the color excess may not be well determined.

By far the best determined ISP for another galaxy comes from the observations by Hough et al. (1987) of the supernova 1986G in Centaurus A (NGC 5128). Indeed, this is probably the only case where the data can be clearly seen to fit a Galactic ISP curve (Fig. 1). The supernova was observed within a day of first discovery, so that the intrinsic polarization was probably low (see, e.g., the spectropolarimetric observations of SN1987A in the LMC, Bailey 1988). It was extremely bright (the galaxy contribution was estimated to be down by 8 mag at V and 3.5 mag at H in an 8 arcsec aperture) giving highly accurate

observations. Spectral coverage included both optical and near infrared wavelengths. Foreground polarization was estimated to be $< 0.5\%$ in the V band, less than a tenth the observed polarization. The position angle of polarization was essentially wavelength independent (again supporting the argument that there was little intrinsic polarization or little contribution from the Galaxy), and was parallel to the well known dust lane.

Values of p_{\max} and λ_{\max} in SN1986G were determined to be $(5.16 \pm 0.04)\%$ and $(0.43 \pm 0.01) \mu\text{m}$, respectively. Thus, λ_{\max} is about 20% smaller than the Galactic average, implying a value of $R_V = 2.4 \pm 0.13$ (using $R_V = 5.6\lambda_{\max}$), compared to a mean value of 3.1 for the Galaxy. The colour excess $E_{B-V} = 1.59 \pm 0.15$ was determined by comparing the observed colors of SN1986G with those of SN1972e (in NGC 5253), at the same time after outburst, for which the reddening was believed to be small. This gives a ratio of p_{\max} to E_{B-V} of $(3.3 \pm 0.3)\%/mag$, a little less than the average of 5%/mag for the Galaxy.

Although observations are relatively sparse, and hence caution is needed in drawing any firm conclusions, it appears that the form of $p(\lambda)$ in external galaxies is typical of the Galaxy, although λ_{\max} is perhaps about 20% lower than the Galactic average. The ratio p_{\max}/E_{B-V} is typical of the Galaxy, and the Galactic $R_V-\lambda_{\max}$ relation also appears to hold. These are quite remarkable results, as the observations cover a large range of galaxy types, the irregular SMC and LMC, the Sb type M31, and the dust lane in the radio elliptical Cen A.

2.2. Integrated Starlight

Substantial work, mostly in the near infrared, is reported in a series of papers by Jones and collaborators (Jones 1993 and references therein). They compared the ratios of J , H and K polarizations with Galactic values, and also the ratio of polarization p_K to color excess E_{J-K} or optical depth τ_K (assuming $\tau_K = 0.50E_{J-K}$). They observed two normal edge-on spiral galaxies, NGC 4565 (Sa) and NGC 5746 (Sa), two LINERS, NGC 660 (SB) and NGC 992 (E(Sc)), three nearby starburst galaxies, M82 (Irr), NGC 253 (Sc) and NGC 3690 (Sm), and three IR-luminous galaxies ($L_{\text{FIR}} > 10^{12} L_{\odot}$), Arp 220 (Pec), IC694 (SBd) and NGC 6240 (Irr), most likely with intense bursts of star formation in their nuclei.

Figure 2 shows the measured K -band polarizations of the above galaxies, plotted against the K -band extinctions. Also shown is SN1986G in Cen A, where the polarization at K (which was not observed by Hough et al. 1987) has been calculated by fitting the modified Serkowski formula of Whittet et al. (1992) to the shorter wavelength data. The p_K , τ_K data points, from the compilation of Jones (1989a) for a variety of Galactic sources, are also included for comparison.

Normal Galaxies and LINERS The edge-on normal spirals, and the LINERS, have degrees of polarization at K relative to their K band extinctions which match well the average relationship found for stars in the Milky Way. However, the polarization at shorter (near-IR) wavelengths is less than expected for Galactic ISP, assuming a value for λ_{\max} of $0.55 \mu\text{m}$ (see Fig. 3 for NGC 4565). Jones (1989b) proposes that for NGC 4565 the wavelength dependence of polarization (measured in four filters between $0.64 \mu\text{m}$ and $2.2 \mu\text{m}$ at a point in the dust lane $6''$ N and $6''$ E of the nucleus) can be explained by the different geometrical depths probed at the different wavelengths. At K the dust-free bulge stars are

viewed through the dusty disk (with the latter acting as a simple screen of dust), while at the shorter wavelengths, where the extinction is substantial, only the first optical depth or so in the disk contributes and thus the observed degrees of polarization are lower. A good fit to the observed data can be obtained using such a model assuming that the polarizing properties of the dust are similar to the Galaxy (Fig. 3).

Starburst and IR-luminous Galaxies The starburst galaxies are observed to have the following properties. The position angle of polarization is parallel to the dust lane, where this can be clearly seen, or the galaxy long axis (e.g. NGC 3690, IC 694, NGC 253 and Arp 220: for the latter galaxy the degrees of polarization at J , H and K are consistent with a simple dust screen). The ratio of the polarization to extinction at K is lower than for stars in the Galactic ISM. The E_{J-K} colors were derived assuming the light from the nuclear region of these galaxies is a combination of normal bulge starlight and emission from H II regions, both reddened by normal interstellar extinction. Jones (1993) considers a number of models to explain the low polarization:

(i) A mix of stars and dust: however, none appears capable of explaining the low polarization.

(ii) Hot dust, which could reduce the polarization by giving (orthogonal) polarization in emission, but this would require at least half the radiation at K to come from hot dust and this would then give $K-L$ colors much redder than observed. Also, hot dust would only lower the polarization at K , whereas low polarizations are also seen at H and J .

(iii) A scrambled magnetic field: this will reduce the polarization, but the path length over which the field randomizes would have to be unreasonably small ($A_V \sim 0.1$). Also, it would be difficult to see how the position angle of polarization aligns with the observed dust lanes in some galaxies if the magnetic field is scrambled.

(iv) Finally, Jones (1993) suggests the most likely model is one in which there are two magnetic fields, with a 'nuclear' poloidal field which is orthogonal to the disk magnetic field (see Fig. 4), with a resultant polarization which depends on the relative optical depths of the two regions with orthogonal polarizations. Evidence for the existence of such fields in the nuclear regions of galaxies undergoing intense bursts of star formation, comes from IR polarimetry of M82 (Dietz et al. 1989), with a position angle of polarization almost perpendicular to the major axis of the galaxy, and from a radio polarization image at centimeter wavelengths (Reuter et al. 1994) which shows a poloidal field structure in the northern halo of M82 (see Fig. 4). Other galaxies which show strong poloidal fields are NGC 4631 (Beck 1996), although not NGC 253.

The poloidal fields, although they can be produced by dynamo action (see, e.g., Ruzmaikin, Shukurov & Sokoloff, 1988), are most likely produced (or at least amplified) by plasma streaming – large scale bipolar winds, arising from the intense star-forming activity in the galaxy nucleus (Bland & Tully 1988; Heckman, Armus & Miley 1987; Baldwin, Wilson & Whittle 1987).

However, care has to be taken in these interpretations, as we will see later that some type Sc normal galaxies have low polarizations (see §3.3).

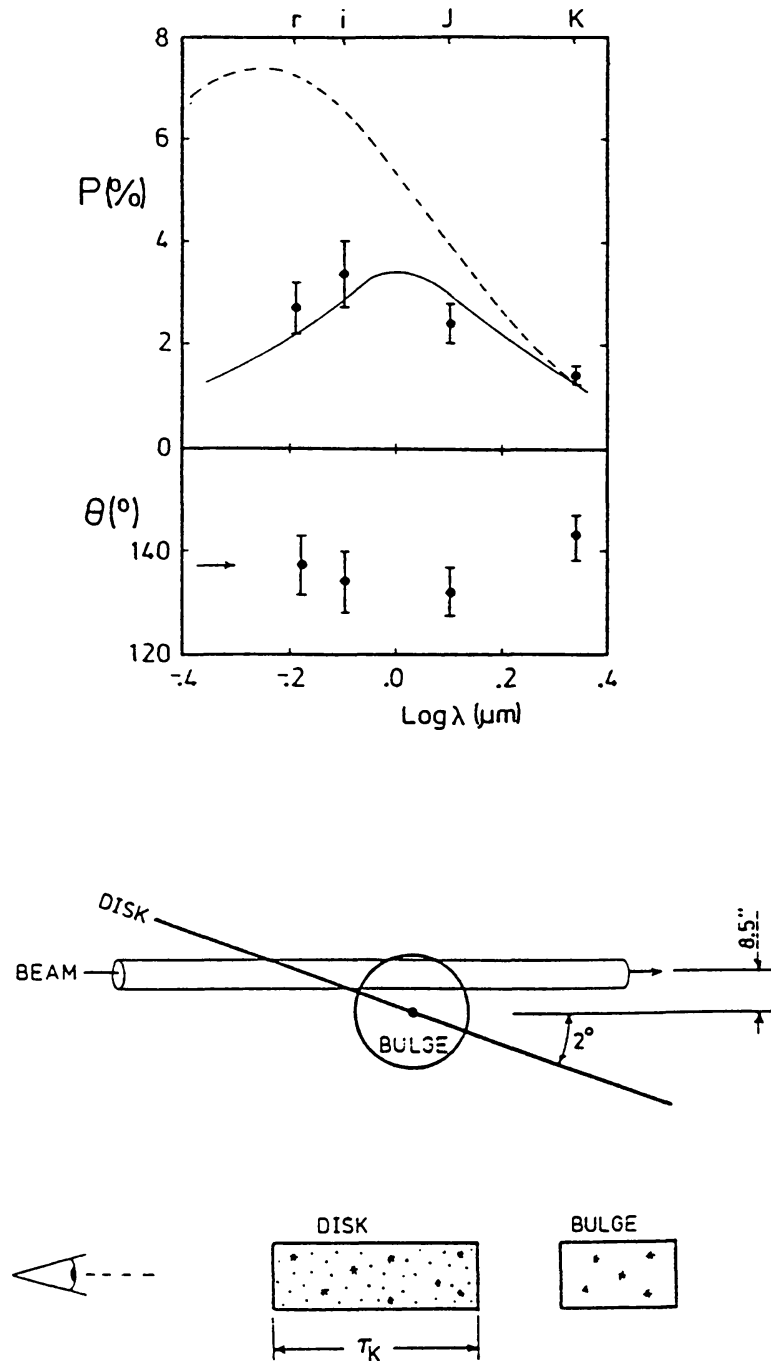


Figure 3. Above: wavelength dependence of polarization degree and position angle in the dust lane of NGC 4565; below: schematic representation of the geometry of the disk and bulge of NGC 4565; from Jones (1989b).

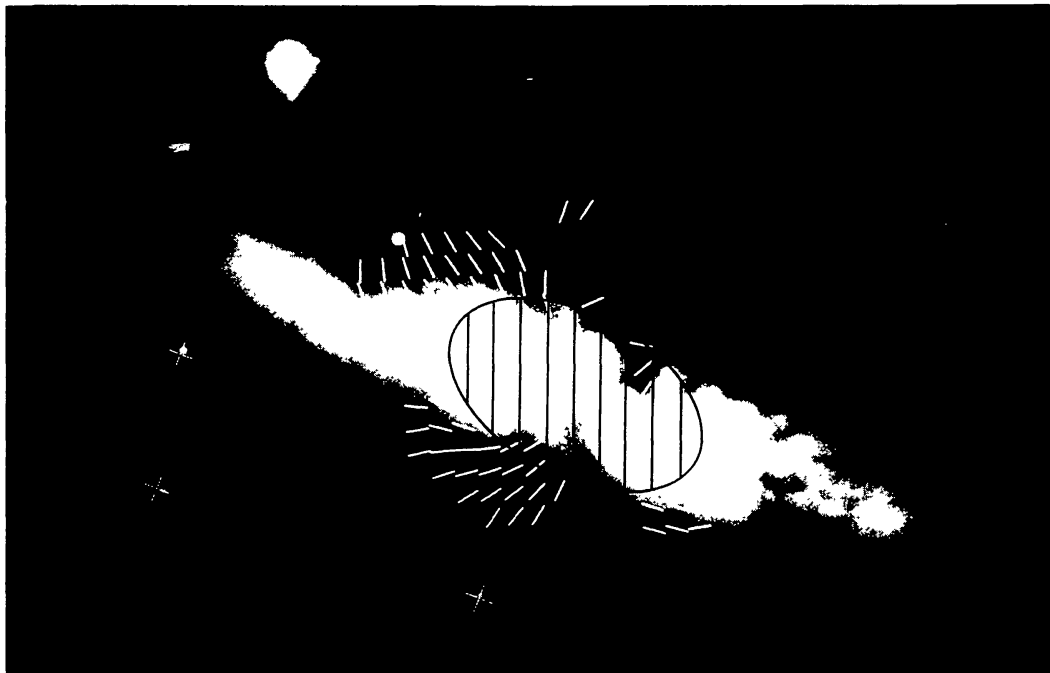
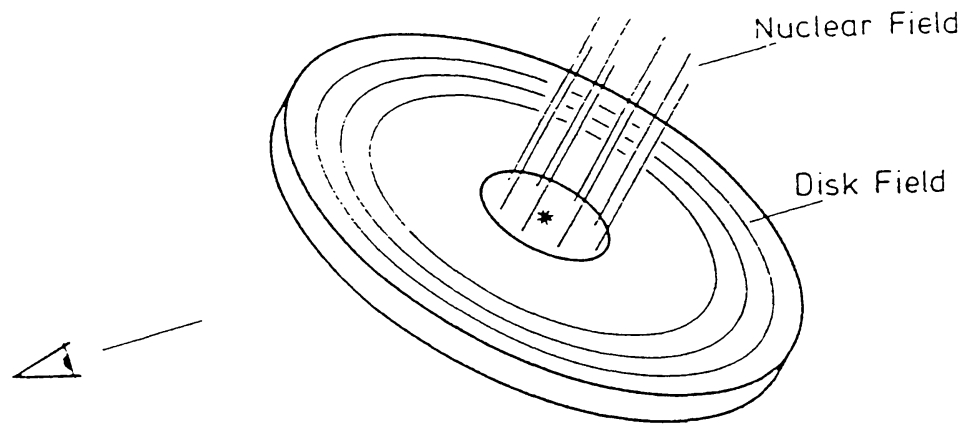


Figure 4. Above: schematic of the proposed magnetic field geometry in the inner bulge and the disk for luminous starburst galaxies (from Jones, Gehrz & Smith, 1990); below: B -field vectors overlaid onto an optical image of M82 (Reuter et al. 1994).

3. Imaging Polarimetry

Accurate imaging polarimetry at optical wavelengths has been available for many years, with the Durham group, led by Mike Scarrott, being particularly productive. At IR wavelengths the situation has been quite different with most imaging polarimetry having been carried out with single beam systems which, even in excellent conditions, are rarely capable of producing polarization accuracies better than about 1%. Hough et al. (1994) have pioneered the use of two beam IR imaging polarimeters, in which both the O-ray and the E-ray are imaged simultaneously, giving an order of magnitude increase in accuracy.

However, even with accurate imaging polarimetry, there are significant problems in interpreting polarization maps at optical and near-IR wavelengths. This is because scattering of radiation can compete with polarization by dichroism. It is more reliable, at least for determining magnetic field structure, to make polarization images at radio wavelengths, where the polarization is produced by synchrotron radiation and scattering is negligible. At wavelengths of a few centimeters the Faraday rotation is low and thus the polarization vectors accurately describe the direction of the galactic magnetic fields. Furthermore, measurements of Faraday rotation at different wavelengths can give additional information on the basic magnetic field structures, with the possibility of distinguishing between axisymmetric and bisymmetric spiral configurations (by measuring the periodicity of the Faraday rotation measure along the azimuthal angle in the disk: Tosa & Fujimoto 1978; see also Fujimoto & Sawa 1990), and thus possibly distinguishing between the primordial and dynamo-driven origins of galactic magnetic fields. An additional advantage of radio observations is that the estimate of the magnetic field strength is much more reliable than at optical wavelengths. Of course, optical and infrared observations, unlike radio, will give information on dust grains.

3.1. Spiral Galaxies

Figure 5 compares radio and optical polarization images of the nearly face-on spiral galaxy M51. The radio image (wavelength of 2.8 cm, upper frame) is from Neininger (1992), the optical (lower frame) from Scarrott, Ward-Thompson & Warren-Smith (1987). In the optical, the open spiral pattern persists from within ~ 200 pc of the galactic nucleus to ~ 1.5 kpc (70 arcsec), for both the bright and dark regions. Beyond this, the same pattern only continues in the dark lanes, with the pattern in the bright arms becoming more irregular. A more continuous pattern in the dark lanes can be understood if the polarization is produced by dichroism as the extinction will be higher here, and the magnetic field in the dark arms may be enhanced due to the compression predicted by density wave theories of the formation of spiral arms in galaxies. In the bright arms, intrinsic polarization of reflection nebulae and bright polarized stars will tend to disrupt the pattern.

The radio map shows a tighter correlation with the spiral arm structure out to much larger distances than the optical map (250 arcsec). Neininger (1992) suggests that this tight correlation cannot be explained by a pure dynamo action as this would not be strong enough, and that the magnetic field actually follows the kinematics of the gas (the rotational energy of the galactic motions is two

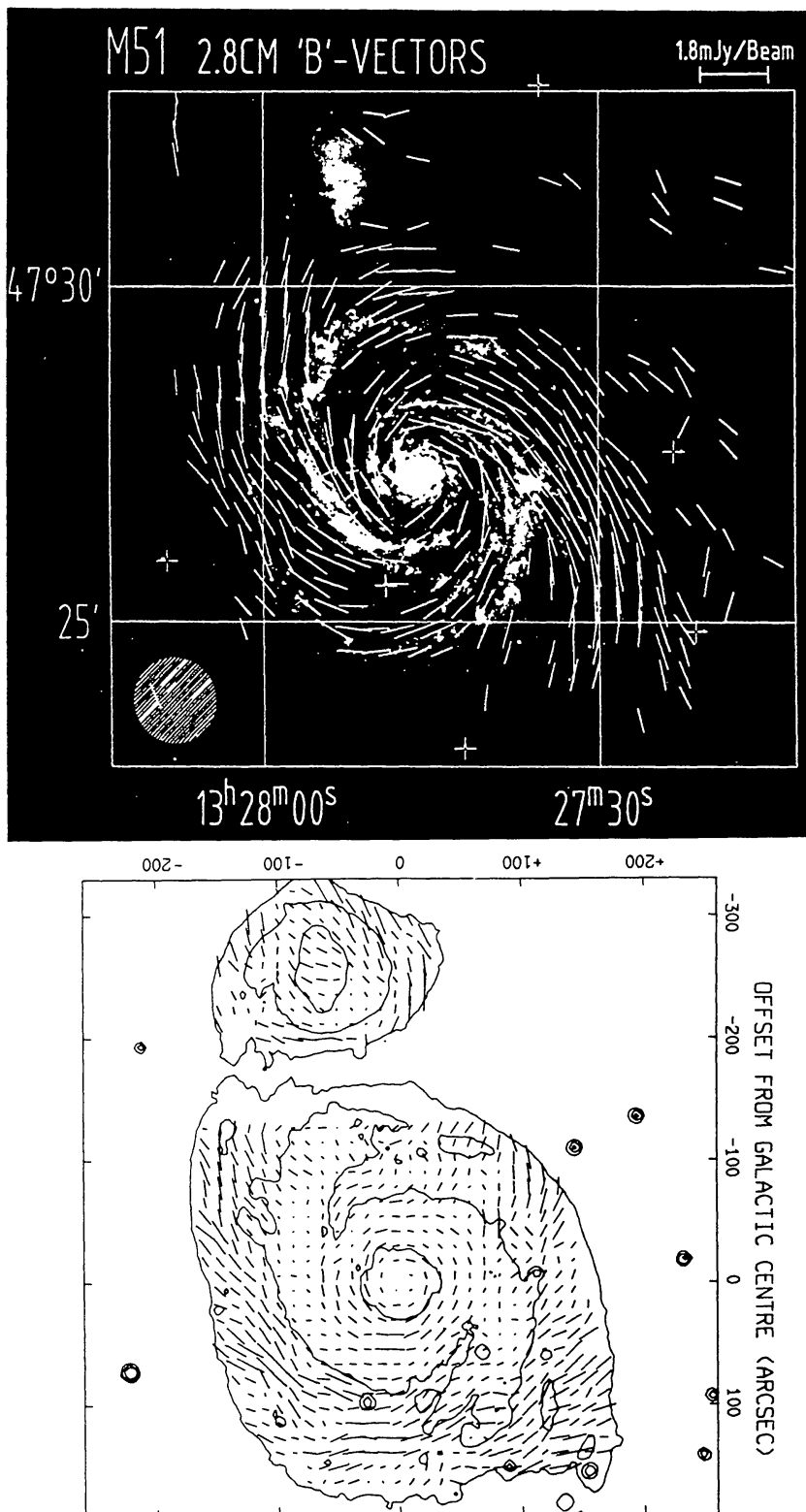


Figure 5. Above: Radio polarization image of M51 at a wavelength of 2.8 cm (Neininger 1992). Below: Optical polarization image of M51 (Scarrott, Ward-Thompson & Warren-Smith 1987).

orders of magnitude more than the magnetic field energy density for a field strength of ~ 10 mG).

Figure 6 shows optical polarization images for three edge-on spirals (Scarrott, Rolph & Semple 1990), which show that there are marked differences between early and late type spirals. The Sa galaxy (M104), has a polarization pattern which extends parallel to and along the dust lane with degrees of polarization $\sim 5\%$, until at the extremities of the dust lane the polarization becomes perpendicular to the long axis of the galaxy. The Sb galaxy (NGC 4565) has smaller degrees of polarization which extend out far less from the nucleus before twisting to become perpendicular to the galaxy long axis. The Sc type galaxy (NGC 5907) has no measurable nuclear polarization and elsewhere the polarizations are perpendicular to the long axis.

Scarrott et al. (1990) propose that the later type galaxies with relatively chaotic dust features do not possess a magnetic field which is uniform or coherent over large distance scales. The polarizations perpendicular to the galaxy long-axis could be produced either by scattering, or (as favoured by Scarrott et al. 1990) by dichroic extinction, with the small tilt of the galaxy to our line of sight producing a net component of magnetic field perpendicular to the plane of the galaxy. They argue that scattering might be more important for the early types with a larger bulge component, which is not seen.

For M104, Scarrott et al. (1990) present the wavelength dependence of polarization between $0.45 \mu\text{m}$ and $0.80 \mu\text{m}$. They find that the best fit Serkowski curve is one with $\lambda_{\text{max}} \approx 0.42 \mu\text{m}$. Although caution needs to be exercised when measuring the ISP of integrated starlight, it is worth noting that this value for λ_{max} is again lower than the average for the Galaxy.

3.2. Starburst Galaxies

For starburst galaxies the polarization pattern is quite different. A galactic scale reflection nebula centred around the nuclear hotspots, and with the scattering taking place in the dusty halo, dominates the optical polarization patterns. Examples are M82 (an almost edge-on starburst galaxy, which is also seen as a reflection nebula in the line of $\text{H}\alpha$; Scarrott, Eaton & Axon 1991a), and NGC 1808 (Scarrott et al. 1993, and references therein), a highly inclined Sbc pec galaxy, seen 33° from the edge-on position (Fig. 7). For NGC 1808 the reflection nebula extends out to ~ 750 pc, with the polarization orientations following the spiral arms of the galaxy on a kpc scale.

3.3. Seyfert Galaxies

Scarrott et al. (1991b) have shown that for the well-known Seyfert NGC 1068 (host galaxy type Sb(rs)II spiral inclined at $20\text{--}40^\circ$ to the sky plane), the large scale optical polarization pattern follows the arm and interarm structure of the galaxy. This suggests a spiral magnetic field configuration, with degrees of polarization higher (typically by a factor of 3) in the dark regions (Fig. 8).

In the central 10 arcsec or so, the polarization pattern is quite different with the appearance of a reflection nebula, which is only clearly seen as a bipolar reflection nebula in the K band image of Packham et al. (1996). In fact, we know from optical spectropolarimetry that NGC 1068 is an obscured Seyfert I (Antonucci & Miller 1985; Young et al. 1995), with our direct view of the nu-

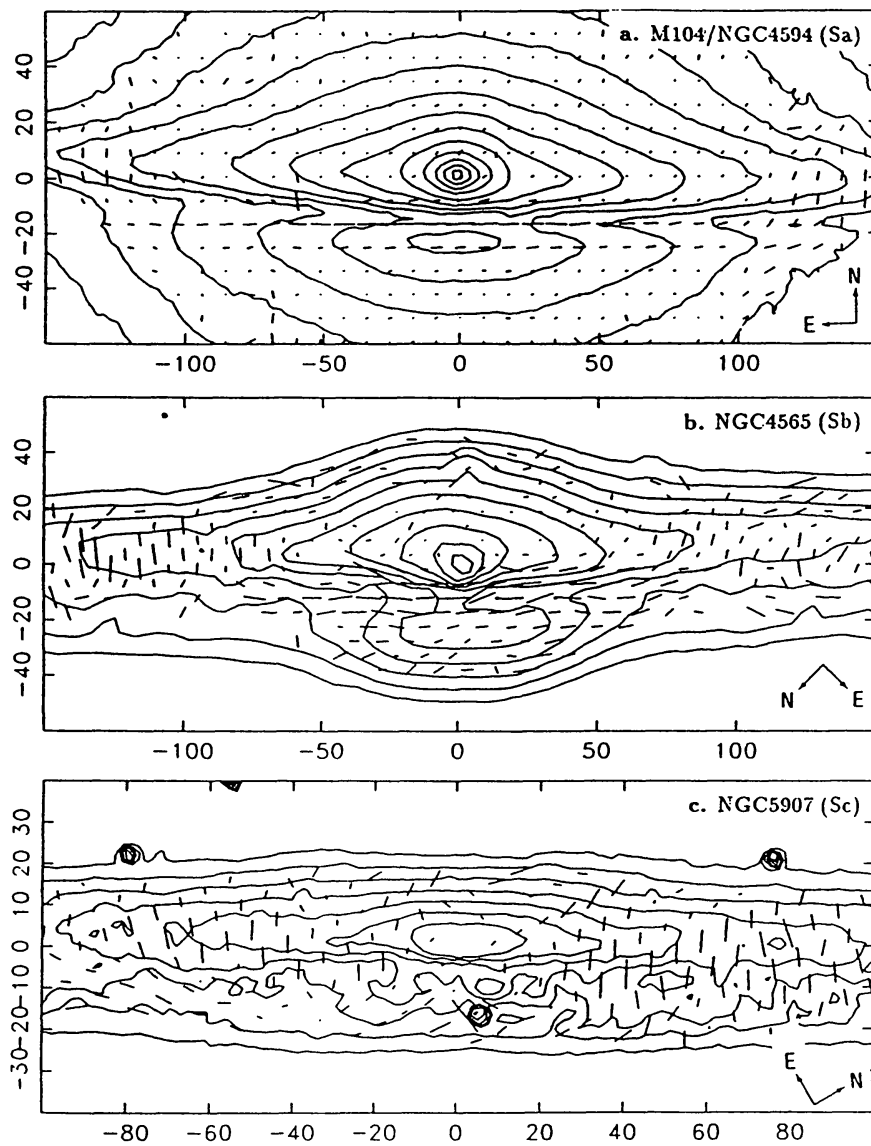


Figure 6. Optical polarization images of three edge-on galaxies (Scarrott, Rolph & Semple 1990): (a) M104; (b) NGC 4565; (c) NGC 5907.

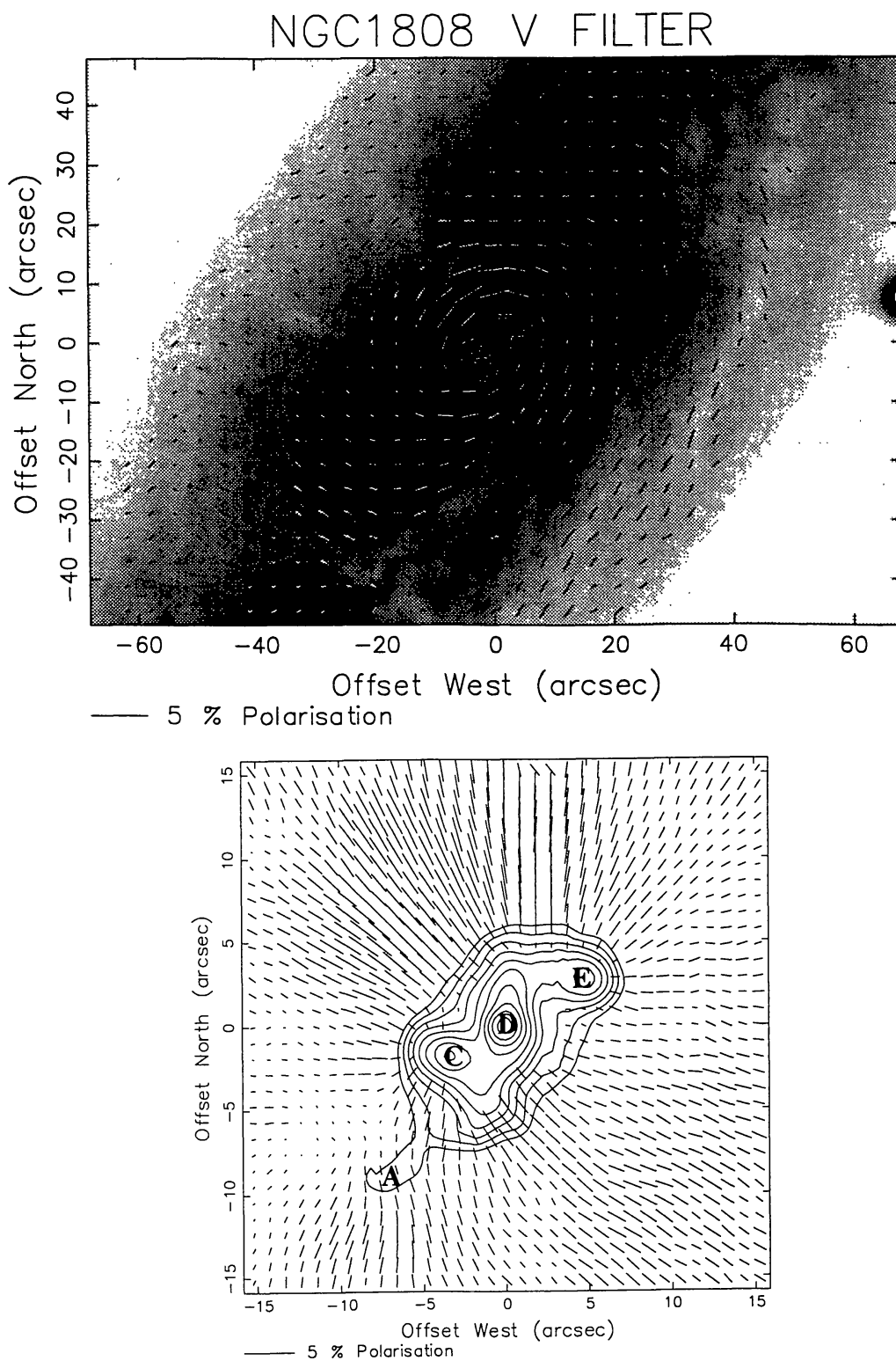


Figure 7. Above: V-band polarization image of NGC 1808; below: central region, with vectors rotated through 90° (from Scarrott et al. 1993).

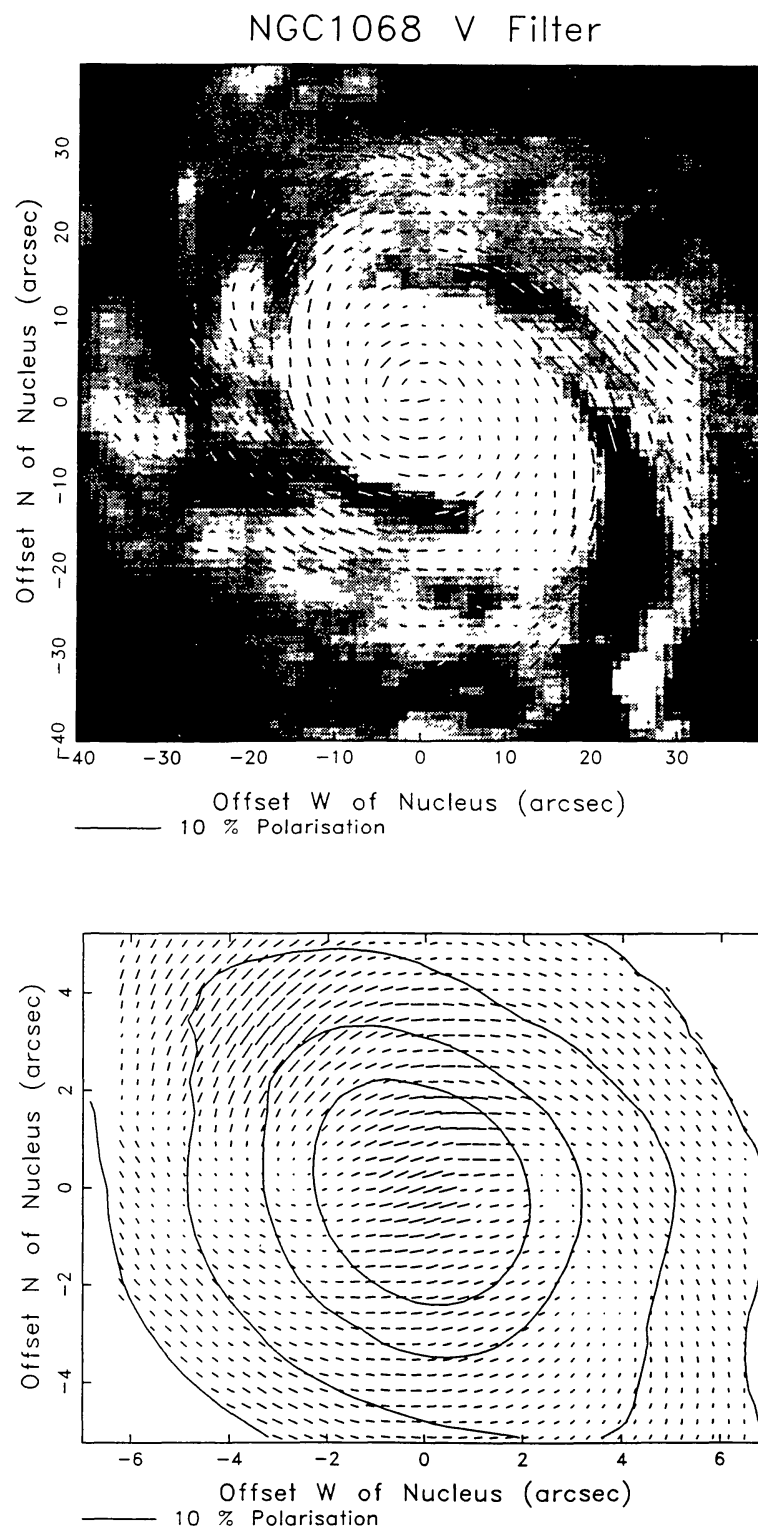


Figure 8. Above: *V*-band polarization image of NGC 1068 (Scarrott et al. 1991b); below: same, for the central ± 5 arcsec.

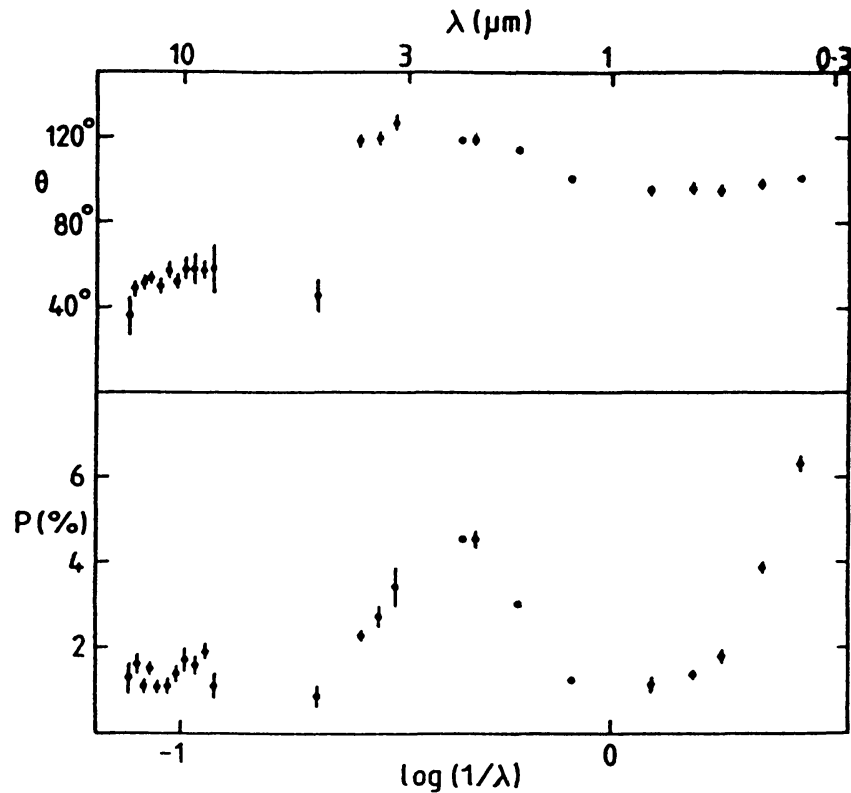


Figure 9. Wavelength dependence of position angle (above) and degree (below) of polarization in the nucleus of NGC 1068 (Bailey et al. 1988).

nucleus obscured by a geometrically thick torus with perhaps a 100 mag of visual extinction. Radiation from the nuclear region is scattered to us by electrons (close to the nucleus) and by electrons and dust (further out), located above and below the obscuring torus.

The wavelength dependence of polarization for the nucleus of NGC 1068 is extremely complex (Bailey et al. 1988), showing a rise in polarization in the near-IR, peaking at about $2\ \mu\text{m}$, and with a flip of 90° in the position angle of polarization at about $4\ \mu\text{m}$ (Fig. 9). Young et al. (1995) have explained this increase in terms of a view through the torus of radiation from hot dust located along the cone axis ('conical' dust, see also Efstathiou, Hough & Young 1995). The polarization is produced by dichroism in the torus, with a magnetic field in the plane of the torus. A good model fit can be obtained assuming a polarization to extinction ratio typical of the Galaxy.

By assuming the conical dust is itself aligned, Efstathiou et al. (1996) are able to model the observed flip of 90° in the position angle of polarization. At around $4\ \mu\text{m}$ the view of the conical dust through the torus becomes optically thin, and the polarization is seen in emission. The conical dust is assumed to be

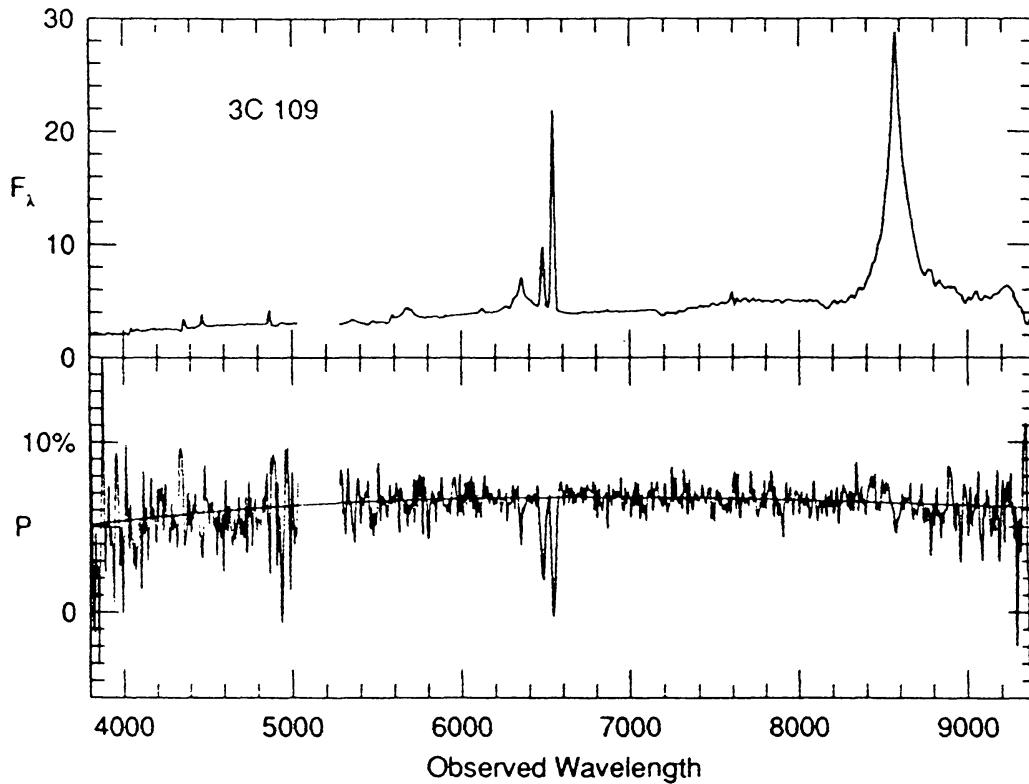


Figure 10. Flux spectrum (above) and spectropolarimetry (below) of the nucleus of 3C109 in visible light (Goodrich & Cohen 1992).

aligned through streaming, with the long axis of the grains parallel to the torus axis and the magnetic field (see Lazarian 1996 and references therein).

It is clear that the alignment of grains is important not only in the ISM, but also in the torus around AGN, and possibly in the hot dust responsible for the near-IR emission in AGN.

4. Optical Spectropolarimetry of a High-Redshift BLRG

Optical spectropolarimetry by Goodrich & Cohen (1992) of 3C109, a $z = 0.31$, highly polarized BLRG, showed that the broad lines and continuum are polarized the same (Fig. 10). After subtraction of a Galactic ISP ($p_{\max} = 1\%$) they were able to fit a Serkowski curve with $p_{\max} = 7.7\%$ and $\lambda_{\max} = 0.65 \mu\text{m}$ to the observed $p(\lambda)$. Reddening was estimated from the Balmer line decrement to be $E_{B-V} > 0.86$, giving $p_{\max}/E_{B-V} < 9\%/mag$; i.e., the grains have a high polarizing ability. Goodrich & Cohen argued that the aligned dust was more likely located in the host galaxy, because the position angle of polarization was not perpendicular to the radio axis. On the other hand, the low polarization of the narrow lines argues for the dust being close in and obscuring only the continuum and BLR, a situation then very similar to that in NGC 1068 (see

§3.3). If this is the case then the polarizing properties of grains in dust clouds around AGN (the dusty torus), appear to be very similar to those in the Galaxy. In either case the presumed quasar core of 3C109 acts as a light beacon allowing the $p(\lambda)$ to be determined.

5. Conclusions and Future Work

The ISP curves for discrete sources show Serkowski-type curves, but far more work can and should be done. For example, is λ_{\max} in our Galaxy higher than in most other galaxies? In general, though, the Galactic ISP curve appears ubiquitous, and can be identified in galaxies out to moderate redshifts ($z > 0.3$). Large wavelength coverage, from $0.35 \mu\text{m}$ to at least $1 \mu\text{m}$, is essential to determine λ_{\max} .

The magnetic field structure is best determined from centimeter radio polarization maps, although Faraday rotation will be a problem for the disks of edge-on galaxies.

Optical and IR imaging polarimetry aids interpretation, especially at high spatial resolution. Excellent instruments are available at optical and near-IR wavelengths.

Aligned grains can occur in the host galaxy of AGN and in the obscuring torus. Important diagnostics are: $10 \mu\text{m}$ spectropolarimetry of the silicate feature seen in type II Seyferts; the switch in polarization from absorption to emission seen in the near-IR for NGC 1068; and millimeter polarimetry for cooler dust emission.

Acknowledgments. It is a pleasure to acknowledge elucidating discussions with Alex Lazarian on grain alignment mechanisms.

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