OPTICAL TO MID-INFRARED POLARISATION OF SEYFERT 2 GALAXIES, A BRIEF REVIEW

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ABSTRACT

We present a brief review of the optical to mid-infrared polarisation characteristics of Seyfert 2 galaxies. We briefly review the unification model for Seyfert galaxies and interpret polarisation observations under this scheme. We discuss the potential importance of our ISOCAM mid-infrared polarisation observations of a selected sample of Seyfert 2 galaxies. We focus on the detailed modelling and observations of NGC1068 and the Circinus galaxy and develop a simple model to predict the mid-infrared polarisation characteristics of our sample of galaxies.

Key words: ISO; infrared polarimetry; active-galaxies; individual; NGC1068; Circinus galaxy.

1. INTRODUCTION

AGN are often considered the most energetic class of galaxy. Their general characteristics are highly ionised emission lines, high nuclear luminosity and rapid variability, suggesting a compact massive central source (e.g. Krolik, 1999). Although the forms of activity seem diverse, they can be unified within a widely accepted model. According to this model most AGN, perhaps all, contain a supermassive black hole (10^7-$10^9 M_\odot$) at their centre. Perhaps the most conclusive evidence for this comes from the kinematics of H_2O mega-masers which are found close to the nuclei of some AGN (Braatz et al, 1996).

1.1. Seyfert galaxies

Seyfert galaxies are the most common class of AGN, making up approximately 98% of all AGN, with 16% of all spiral galaxies containing a Seyfert nucleus (Maiolino and Rieke, 1995). They were the first discovered and classified AGN class (Seyfert, 1943) and are generally divided into Seyfert 1s and Seyfert 2s, depending on their optical emission line widths (Osterbrock, 1989); Seyfert 1–broad and narrow permitted lines and narrow forbidden lines directly observed, Seyfert 2–only narrow permitted and forbidden lines directly observed. The broad line widths are generally 3,000 kms^{-1} whilst the narrow line widths are more typically 500 kms^{-1}.

1.2. The unified Seyfert model

The unified model for Seyfert galaxies proposes that all types of Seyfert galaxy are fundamentally the same, however, the presence of a dusty molecular "torus" obscures the broad line emission in many systems. In this picture the classification of Seyfert 1 or 2 depends on the inclination angle of the torus to the line of sight (Antonucci, 1993). The most convincing evidence for this unified model comes from optical spectropolarimetry. Using this technique, the scattered radiation from the broad line region (BLR) of many Seyfert 2 galaxies is revealed in the form of broad lines in the polarised flux (e.g. Antonucci and Miller, 1985, Young et al, 1996a, Heisler, Lumsden and Bailey, 1997).

Independent strong support for this model has been given by X-ray observations, showing that Seyfert 2 galaxies are characterised by strong absorption, corresponding to column densities $>10^{22}$cm^{-2} whilst Seyfert 1 galaxies are relatively unabsorbed (e.g. Turner et al, 1997, Maiolino et al, 1998). This result is most readily understood if, indeed, all Seyfert galaxies contain a luminous compact central source that is subjected to viewing angle dependent absorption.

Direct imaging of the torus is technically demanding due to its (predicted) small size (e.g. Efstathiou, Hough and Young, 1995, Granato, Danese and Franceschini, 1997, Alexander et al, 1999a). Perhaps the most convincing direct evidence of a Seyfert torus comes from observations of the HCN molecule (Jackson et al, 1993), which traces dense molecular gas, and near-IR imaging polarimetry (Young et al, 1996b) of NGC1068. These images show a large nuclear structure of ~200 pc in extent, approximately perpendicular to the [OIII]λ 5007 emission cone and radio lobe emission.

Indirect imaging support for tori comes from ground-based narrow band imaging (e.g. Wilson and Tsvetanov, 1994), high resolution HST imaging (e.g.

Capetti et al 1997, Falcke, Wilson and Simpson, 1998) and imaging-polarimetry (e.g. Packham et al, 1997, Ruiz et al, 1999, Lumsden et al, 1999, Tadhunter et al, 1999) which have shown a number of objects with nuclear "cone-like" structures, presumably collimated by the torus, see figure 1.

A simple measure of the covering fraction of the torus can be deduced from the ratio of Seyfert 1 to Seyfert 2 galaxies. An accurate measure is difficult to determine, depending on the selection and classification of the object sample and possibly on the luminosity of the source, but appears to lie between 1:1 and 1:8 with a most likely value of 1:2 (Lawrence, 1991). This suggests an opening half-angle of the torus of $\sim$40 degrees, in good agreement with the constraints placed by narrow band [OIII]λ 5007 imaging and imaging-polarimetry observations.

In section 2 we briefly review the polarimetry observations and mechanisms of Seyfert 2 galaxies focusing on NGC1068 and the Circinus galaxy (hereafter Circinus). In section 3 we describe and discuss our ISOCAM polarimetry observations. In section 4 we draw conclusions.

2. OPTICAL TO MID-INFRARED POLARISATION OF SEYFERT 2 GALAXIES

2.1. Optical wavelengths

Approximately 30 Seyfert 2 galaxies have shown broad Hα or Hβ emission lines in polarised flux and therefore scattered emission at optical wavelengths (Alexander, 1998). In the nuclear region of NGC1068 electron scattering is dominant whilst in the off-nuclear regions dust scattering dominates (Miller, Goodrich and Matthews, 1991, Inglis et al, 1995, Young et al, 1995). By contrast, although there is undoubtably scattering in the nucleus of Circinus, due to the detection of polarised broad Hα, the dominant optical polarisation process appears to be dichroic absorption from the interstellar medium of the galaxy (Oliva et al, 1998, Alexander et al, 1999b).

2.1.1. Scattering

In Seyfert 2 galaxies the optical depth of the scatterers is low and therefore the degree of polarisation for Thompson and Rayleigh scattering is simply dependent on the scattering angle

$$P = \frac{1 - cos^2(\Theta)}{1 + cos^2(\Theta)} \qquad (1)$$

However, the polarisation produced from scattering in a more realistic "cone-like" configuration with the number density of scatterers dependent on the distance from the central source is more complex (see Young et al, 1995). The position angle of polarisation (defined as the position angle of the electric vector) from scattered radiation is perpendicular to the scattering plane, as defined by the plane of the source and scatterers. In Seyfert 2 galaxies this gives rise to a partial centro-symmetric scattering pattern with the position angle of polarisation perpendicular to the direction of the central source (e.g. Capetti et al, 1995, Lumsden et al, 1999).

The efficiency of Thomson scattering is independent of wavelength whilst Rayleigh scattering is proportional to the forth power of the radiation frequency. In Seyfert 2 galaxies the dominant nuclear scattering particles are generally electrons (e.g. Young et al, 1995, 1996a, 1996b, 1998, Packham et al, 1997).

2.1.2. Dichroic absorption

Dichroic absorption is the process of selective extinction. To produce a bulk selectivity, a mechanism is required to force an abundance of absorbers to align in one orientation, implying that the absorbers are not spherical.

In astronomical objects, dichroism probably arises through the alignment of non-spherical dust grains in a magnetic field, with the small axis of the dust grain preferentially parallel to the magnetic field. Radiation passing through such a medium becomes polarised with a position angle parallel to the direction of the magnetic field. The alignment process is not well understood in detail but the classical theory is the Davis-Greenstein mechanism (Davis and Greenstein, 1951) which achieves alignment through paramagnetic relaxation (see Lazarian, 1995a,b for a review).

The degree of polarisation from dichroic absorption in the interstellar medium of the Galaxy is found to have a wavelength dependence given by

$$\frac{P_{\lambda max}}{P_\lambda} = exp(-Kln^2\frac{\lambda max}{\lambda}) \qquad (2)$$

Where λmax is typically found to be between 400 and 800nm and K (the width of the curve peak) found empirically to initially be 1.15 (Serkowski et al, 1975) and later as 0.01+1.66λmax (Whittet et al, 1992). In the infrared the equation is transformed into a power law (Martin and Whittet, 1990) of very similar spectral index to that of the infrared extinction law (Landini et al, 1984), showing the close association between the two processes. The degree of polarisation is proportional to the extinction.

2.2. Near-infrared wavelengths

Observations have shown that the degree of polarisation in many Seyfert 2 galaxies increases with wavelength into the near-infrared (Brindle et al, 1990, Young et al, 1996a), defined here as between 1.0 and 2.5μm. Detailed modelling of NGC1068 (Young et al, 1995) has shown that the near-infrared polarisation in unlikely to result from scattering of nuclear infrared photons, unless the nuclear spectrum is extremely red. The most likely explanation for the increase in near-infrared polarisation is dichroic absorption produced by the passage of radiation through

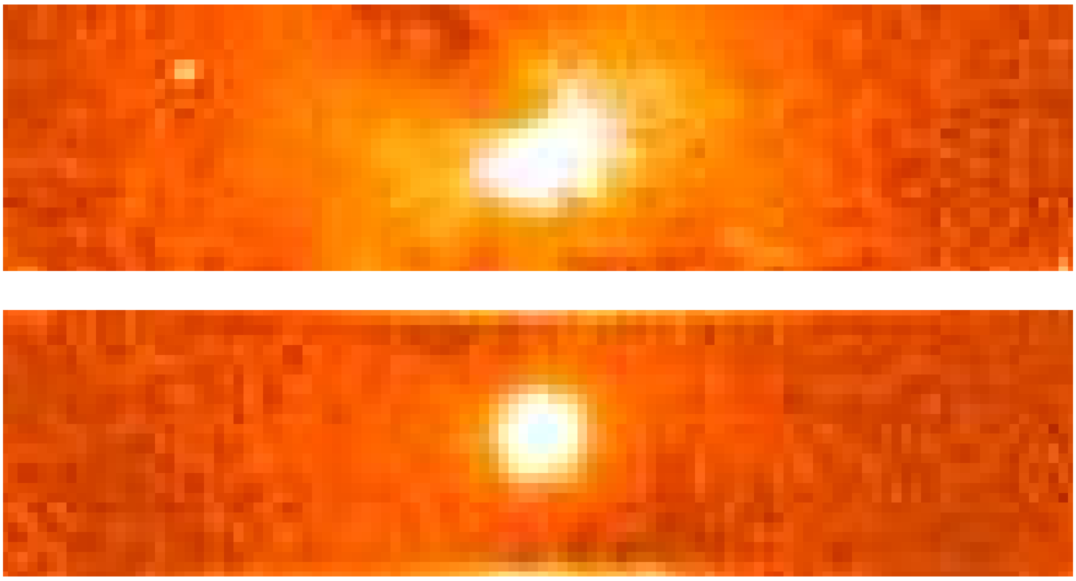

Figure 1. Near-IR polarised flux images of Circinus, J band (top) and K band (bottom), showing the change in polarised structure from predominantly scattering to predominantly dichroism. Taken from Ruiz et al (1999).

aligned dust grains within the torus, with the line of sight to the infrared emitting regions (presumably hot dust) having a lower optical depth than to the BLR. The polarisation position angle is found to be perpendicular to the [OIII]λ5007 emission cone and radio lobe emission, implying that the magnetic field, as projected on the sky plane, lies in the plane of the torus, at least at a height from the torus equator of $\sim$1 pc where the near-infrared emission is likely to be viewed. A similar model has been successfully applied to the polarimetry observations of Circinus (Alexander et al, 1999b) and other Seyfert galaxies (Young et al, 1996a, 1996c, 1998, Packham et al, 1997).

This change in polarisation mechanism is evident in the near-infrared polarised flux images of Circinus (Ruiz et al, 1999). In the J band (1.25μm) bipolar scattering cones are observed, with the North West cone coincident with the single-sided [OIII]λ5007 ionisation cone (Marconi et al, 1994) whilst in the K band (2.2μm) a more compact structure is observed, see figure 1. The simpliest explanation for this is the change in polarisation mechanism from scattering to dichroism, in agreement with the spectropolarimetric model (Alexander et al, 1999b).

2.3. Mid-infrared wavelengths

NGC1068 is the only Seyfert 2 galaxy to have been detected in polarisation at mid-infrared wavelengths, defined here as between 4 and 15μm. Aperture polarimetry of the 8 to 13μm region around the 9.7μm silicate absorption feature of NGC1068 shows a flat polarisation (within the errors) of $\sim$1.4% (Aitken et al, 1984), suggesting that the polarisation is not due to dichroic absorption. Near-infrared to mid-infrared aperture polarimetry shows a sharp change in polarisation position angle of approximately 90 degrees at 4.5μm (Bailey et al, 1988), suggesting a change in polarisation mechanism from that found at near-infrared wavelengths. Recent near-infrared to mid-infrared imaging polarimetry has confirmed this position angle flip and has shown that the mid-infrared polarisation is produced in an extended (few arcsecond) region around the nucleus (Lumsden et al, 1999).

If absorption by aligned dust grains is responsible for producing the polarisation at near-infrared wavelengths then at longer wavelengths, as the optical depth decreases and the thermal flux from the warm grains increases, the dust grains will produce polarised radiation in emission. Figure 2 shows the expected wavelength change for optical depth in dominant polarisation from dichroic absorption to dichroic emission (based on equation 3 with the change in dominance ocurring when τ_λ <1).

2.3.1. Dichroic emission

Dichroic emission in this context has two distinct characteristics: the plane of polarisation is perpendicular to that seen in absorption (a rotation of 90 degrees is observed in the position angle) and the polarisation is essentially wavelength independent. The intrinsic polarisation seen as a result of aligned dust grains in absorption and emission, from Hildebrand (1988) is

$$P_{em} = \frac{P_{abs}}{\tau_\lambda} \qquad (3)$$

Due to the similar infrared power law nature of dichroic absorption in the interstellar medium and the extinction law, the instrinsic degree of polarisation in emission should be constant at infrared wavelengths, assuming that the same grains are producing the absorption. Therefore to determine the degree of polarisation it is just necessary to know the extinction and polarisation from absorption at a single wavelength. It should be noted that the observed polarisation may deviate from this calculated value due to dilution from unpolarised emission.

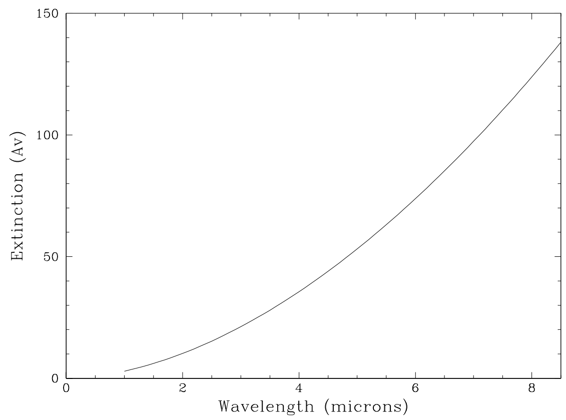

Figure 2. The calculated wavelength range for the change from dichroic absorption to emission.

Efstathiou, McCall and Hough (1997) modelled the expected dichroic polarisation from aligned dust grains using the radiative transfer and torus configuration described in Efstathiou and Rowan-Robinson (1995). They found that the 90 degree position angle flip is well produced by a change from dichroic absorption to dichroic emission in the torus and that (1) the wavelength at which the position angle flip occurs is weakly dependent on all parameters except the optical depth and (2) the silicate absorption feature is flat in polarisation for all torus inclinations except that edge-on (i.e. the most extreme configuration).

3. THE ISOCAM SAMPLE

3.1. Observations

We have used ISOCAM with polarimetry (CO5) to observe at mid-infrared wavelengths a number of Seyfert 2 galaxies with known optical polarisation. Most of the objects have had broad lines detected in polarised flux from which an estimation of the system inclination could be determined.

Our principal aim is to determine the wavelength at which the polarisation position angle changes by 90 degrees, indicating the transition from polarisation by dichroic absorption to dichroic emission. This, together with the known inclination of the system, will enable the optical depth of the torus to be determined. It would also confirm that the polarisation mechanism at near and mid infrared wavelengths is dichroism and thereby confirm the direction of magnetic fields in the torus.

Our full sample of galaxies, the ISOCAM filters used and estimated extinctions to the near-infrared emission region (taken from Alonso-Herrero, Ward and Kotilainen, 1997 and Young et al, 1996a,c) are presented in table 1.

Within our sample we have a selection of different galaxy types. F05189-2524, F23060+0505 and MKN463E are ultraluminous infrared galaxies (Sanders and Mirabel, 1996) with Seyfert 2 characteristics and detected polarised broad lines. NGC0034, NGC7172 and NGC1808 are galaxies that have a substantial starburst fraction in addition to the Seyfert nucleus and have not been detected with polarised broad lines. NGC1068, NGC7674 and IC5063 are powerful Seyfert dominated galaxies and have detected polarised broad lines. All of these galaxies would be approximately point sources with the relatively poor spatial resolution of ISOCAM, with the possible exceptions of NGC0034, NGC7172 and NGC1808 which, with considerable starburst activity, may show a more extended structure.

Table 1. The ISOCAM Seyfert 2 sample.

Galaxy	Filters	A_V (mags)
F05189-2524	lw2	16
F23060+0505	lw2,lw3	20
IC5063	lw2,lw3	32
MKN463E	lw2,lw3	17
NGC0034	lw2	-
NGC1068	lw1,lw2,lw9	45
NGC1808	lw4,lw7	-
NGC7172	lw2	-
NGC7674	lw2,lw3	20

Notes. Filter peak wavelengths: lw1=4.5, lw2=6.75, lw3=14.3, lw4=6.0, lw7=9.6, lw9=14.9μm.

3.2. Predictions

Based on our model, the range in estimated near-infrared extinctions for our galaxy sample suggest that the change in dominant dichroic polarisation mechanism from absorption to emission should occur within the 3 to 5μm range (see figure 2). We can estimate the expected range in polarisation based on the range of dichroic absorption polarisation. As the polarisation by dichroic absorption is proportional to the optical depth and scaled according to P_{max}, we can estimate the polarisation from the range of P_{max}/A_V. From the range of model dependent values found by Young et al (1996a) we would expect the polarisation from dichroic emission to be between 0.3% and 2.5%.

4. CONCLUSIONS

We have reviewed the optical to mid-infrared polarisation characteristics of Seyfert 2 galaxies and discussed the potential importance of ISOCAM observations. We have predicted the basic polarisation properties of our ISOCAM observations of a selected sample of Seyfert 2 galaxies. Based on the detailed modelling and observations of NGC1068 and Circinus and a simple model developed here, we have shown that the most likely dominant mid-infrared polarisation is dichroic emission. The expected degree of polarisation from this mechanism is from 0.3% to 2.5%.

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