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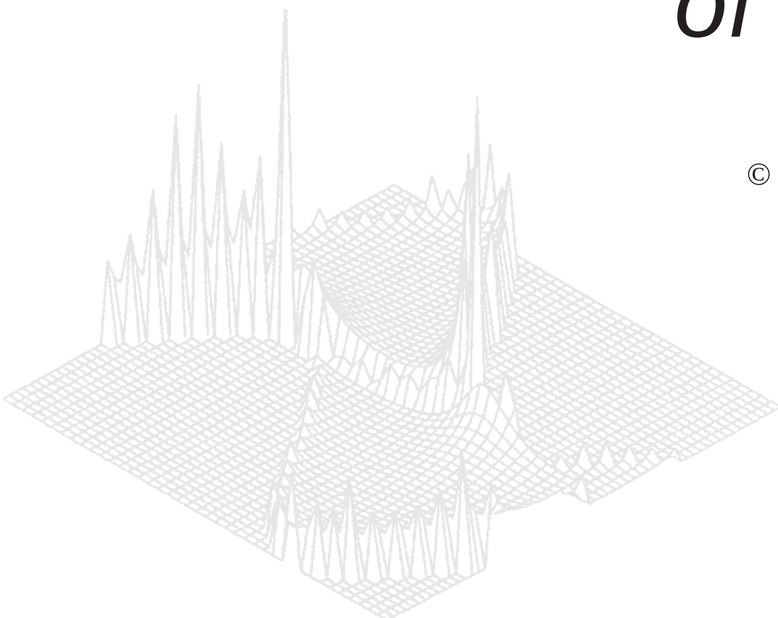

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Dependence of Faraday Effects on Radio Luminosity and Redshift

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Abstract

Quantitative estimates are provided for the influence of luminosity selection effects present in a bright source sample on the observed correlation of the depolarisation rate $\lambda_{1/2}$ with redshift z. It is shown that the observed correlation is partly intrinsic and partly due to luminosity effects. More specifically, we find that ~46% of the observed $\lambda_{1/2}$ correlation with z can be attributed to strong luminosity selection effects in the sample. This shows that a significant fraction (~54%) of the observed correlation is cosmological in origin. It is concluded that there is a cosmological evolution of $\lambda_{1/2}$, over and above that resulting from luminosity selection effects, which may be related to the epoch dependent properties of the ambient medium through which the radio source components propagate.

1. Introduction

A study of the correlation of polarisation characteristics of extragalactic radio sources with other physical source parameters is necessary in our understanding of the nature of these sources, as well as the properties of the intervening medium. Conway and Gilbert (1970) first noted that extragalactic radio sources display a strong correlation between Faraday effects and redshift z. This was later confirmed by Kronberg *et al.* (1972) who found that the depolarisation rate $\lambda_{1/2}$ (the emitted wavelength at which the polarisation drops to one-half of its maximum value) decreases monotonically with increasing z. In addition, they showed that $\lambda_{1/2}$ also correlates with radio luminosity P, but argued that the primary correlation is with z. However, Morris and Tabara (1973) showed that the correlation is with P and not with z, in contrast to Kronberg *et al.* (1972). At the same time, a correlation was also found between $\lambda_{1/2}$ and linear size D. However, as observed by Conway *et al.* (1974), these correlations are different representations of one and the same observational phenomenon. Faraday effects arise when polarised radiation passes through any plasma containing a magnetic field. This depolarisation may be caused by thermal gas within or outside the radio source component. The depolarisation rate defined above appears to be the most common measure of depolarisation (see Garrington *et al.* 1991).

Several other workers (e.g. Saikia and Salter 1988 and references therein; Tadhunter *et al.* 1992; Cimatti *et al.* 1993) have investigated the form of dependence

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of the various Faraday effects on redshift and radio luminosity and it is not yet conclusive whether the primary correlation is with redshift or luminosity. Usually, in flux density-limited samples, both luminosity and redshift are coupled due to the ubiquitous Malmquist bias.

Following our earlier paper (Ubachukwu *et al.* 1996), we show here that some quantitative estimates can be provided for the effect of luminosity on the observed correlation between depolarisation rate and redshift.

2. Variation of Luminosity with Redshift and Its Effect on the Dependence of Depolarisation Rate on Redshift

The high luminosity extragalactic radio source population is known to evolve with cosmological epoch. The evolution of radio sizes appears to have been fairly well established both observationally (e.g. Oort *et al.* 1987; Kapahi 1989; Singal 1993) and theoretically (e.g. Gopal Krishna and Wiita 1987; Rosen and Wiita 1988; Ubachukwu *et al.* 1991). There is also a strong indication of evolution in both space density and/or radio luminosity and spectral index (see Windhorst 1984; Sandage 1988; Windhorst *et al.* 1989; Ubachukwu *et al.* 1993). Furthermore, the detection of Faraday effects in high redshift sources, as compared to their low redshift counterparts, suggests cosmological evolution (e.g. Antonucci 1984; Scarrott *et al.* 1990; Cimatti *et al.* 1993). As pointed out in Section 1, it has not been easy distinguishing between the effects of luminosity and genuine evolution due to strong selection effects in most well-studied source samples. We describe below a simple formalism for estimating the contribution of luminosity effects to the observed correlation between other physical parameters and redshift with particular reference to depolarisation rate.

Following our earlier paper (Ubachukwu *et al.* 1996), we write the variation of luminosity with redshift as a simple power-law function

$$P = P_0(1+z)^{\beta}, \tag{1}$$

where $P_0 = P(z=0)$ and β can be assumed constant if the P–$(1+z)$ correlation is entirely due to selection effects (see Ubachukwu *et al.* 1993). We also adopt a functional dependence of the depolarisation rate $\lambda_{1/2}$ on radio luminosity and redshift respectively of the form (e.g. Inoue and Tabara 1982)

$$\lambda_{1/2} = a_1 - m\log(P/P*)\,, \tag{2}$$

$$\lambda_{1/2} = a_2 - n\log(1+z)\,, \tag{3}$$

where a_1 and a_2 are constants and $P*$ is a normalising luminosity. We can use equation (1) in (2) to show that

$$\lambda_{1/2} = a_3 - m\beta\log(1+z)\,, \tag{4}$$

where

$$a_3 = a_1 m\log(P_0/P*)\,. \tag{5}$$

It therefore follows from equations (3) and (4) that if the observed $\lambda_{1/2}$–(1+z) correlation is entirely due to selection effects (i.e. arising from the P–z correlation), then we can write

$$n = m\beta\,. \quad (6)$$

Otherwise, we have

$$x = n - m\beta\,, \quad (7)$$

where x is the residual redshift dependence after correcting for that which results from luminosity selection effects. Equation (7) thus makes it possible for a quantitative estimated to be made concerning the influence of luminosity on the observed $\lambda_{1/2}$–z correlation.

3. Analysis and Results

The present analysis is carried out using the data compiled by Garrington *et al.* (1991). This sample consists of 47 sources (largely quasars) with complete redshift information. The radio luminosity was estimated from the observed flux density at the emitted frequency of 5 GHz. Values of the density parameter $\Omega_0 = 1$ and Hubble constant $H_0 = 50$ km/s/Mpc were adopted. The values of the depolarisation rate $\lambda_{1/2}$ used were calculated from the values of Faraday dispersion using (e.g. Garrington and Conway 1991)

$$\lambda_{1/2} = 0\cdot 86(1+z)/\Delta_{1/2}\,, \quad (8)$$

where D is the Faraday dispersion. The present analysis covers only the counter-jet side which shows a stronger correlation with other parameters than the jet side (see Garrington *et al.* 1991; Garrington and Conway 1991).

We first investigate the dependence of $\lambda_{1/2}$ on z and radio luminosity independent of each other by fitting the observed data to equations (2) and (3) respectively. The results and their standard errors give

$$\lambda_{1/2} = 1\cdot 14 - (0\cdot 0013 \pm 0\cdot 0005)\log P\,, \quad (9)$$

$$\lambda_{1/2} = 0\cdot 52 - (0\cdot 0093 \pm 0\cdot 0025)\log(1+z)\,, \quad (10)$$

with correlation coefficients $r \approx 0\cdot 42$ and $-0\cdot 54$ respectively. Both correlations are quite significant. We adopted $\log P^* = 25$.

In order to investigate the effect of luminosity on the above results, we fitted the observed $\log P$–$\log(1+z)$ data into equation (1). We obtained $\beta = 3\cdot 35$ and $\log P = 22\cdot 6$ with $r \approx 0\cdot 63$. Using $\beta = 3\cdot 35$ in equation (6), together with the values of $m = 0\cdot 0013$ and $n = 0\cdot 0093$ given in equations (9) and (10) respectively, shows that $n \neq m\beta$. Hence, from equation (7), which gives the residual redshift dependence we obtain

$$x = 0\cdot 0093 - 0\cdot 0013 \times 3\cdot 35 \approx 0\cdot 005\,. \quad (11)$$

This shows that the observed $\lambda_{1/2}$–z correlation is not entirely due to selection effects, but only ∼46% can be attributed to luminosity, the rest (∼56%) being intrinsic. A recent similar analysis based on spectral index (Ubachukwu *et al.* 1996) indicated a much stronger luminosity effect (∼54%).

4. Discussion

We have carried out quantitative analyses of the dependence of the depolarisation rate $\lambda_{1/2}$ on radio luminosity P and redshift z for a bright source sample. Our results show that $\lambda_{1/2}$ is significantly correlated with both P and z independently. However, when the effects of luminosity are corrected for, we found that a fairly significant fraction (∼46%) of the observed $\lambda_{1/2}$–z dependence could be attributed to the stronger P–z correlation present in the sample. Nevertheless, there is still a strong indication that the observed $\lambda_{1/2}$–z correlation is not entirely due to selection effects; quite a significant fraction (∼54%) could be cosmological in origin. This result is consistent with that obtained previously by Kronberg *et al.* (1972) and partly confirmed more recently by Garrington and Conway (1991).

The study of the relationship between depolarisation characteristics and other source properties is necessary in interpreting whether the observed Faraday effects are intrinsic to the source or are caused by the magneto-ionic material in the surrounding medium. An earlier indication of a correlation between $\lambda_{1/2}$ and linear size (e.g. Strom 1973) appears to be a secondary effect of the redshift dependence (see Garrington and Conway 1991). This indicates that the depolarising medium is probably not within the source. There is a number of recent observational clues which independently suggest that the cause of the observed depolarisation may be external to the source. McCarthy *et al.* (1991) have given evidence of a correlation between the extended line emission regions (EELR) and armlength (see also Liu and Pooley 1991). This is particularly true for radio galaxies. On the other hand, Garrington and Conway (1991) found that depolarisation strongly correlates with both jet-sidedness and armlength, but could not find any correlation between EELR and jet-sidedness. They therefore argued that the major contribution to the depolarisation arises from an external galactic halo of ionised gas and none from the EELR. Kato *et al.* (1987) have suggested that the dense medium around the nucleus of compact steep spectrum sources, which stops source expansion and also subsequent formation of extended structure, could be responsible for the observed Faraday effects.

Gopal-Krishna and Wiita (1987) developed a model for radio size evolution in which a pressure-matched interface between the gaseous galactic halos and the much hotter intergalactic medium (IGM) moves closer to the galactic nuclei with rising redshift. The density of this gas is expected to evolve as $(1+z)^3$. If the galactic halo is responsible for the observed polarisation, a suggestion by Garrington and Conway (1991), then the redshift dependence of the properties of the halo–IGM interface may be responsible for the observed $\lambda_{1/2}$–z correlation. We are therefore led to conclude that there is a strong indication of evolution of the depolarisation rate with cosmic epoch, over and above that resulting from luminosity selection effects, and which may be related to the epoch-dependent properties of the ambient medium through which the radio source components propagate.

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