THE OPTICAL POLARIZATION OF QSOs

Richard L. Moore
California Institute of Technology, Pasadena, CA, U.S.A.

Recent optical polarization studies indicate that there are two distinct types of QSOs - "normal" QSOs with $P \lesssim 1\%$, and highly polarized QSOs (HPQs) with $P > 3\%$. The HPQs are very similar to BL Lac objects, yet still share some properties of normal QSO's (e.g. strong emission lines). Our results generally support the relativistic beaming model for QSOs; however, certain key predictions of this model are not observed.

I. POLARIMETRIC PROPERTIES OF QSOs

An extensive survey of the optical linear polarization of QSOs has recently been completed by the author, in collaboration with Drs. H.S. Stockman and J.R.P. Angel. The results of this survey and the implications of the results are briefly summarized in this paper.

A primary conclusion from our survey is that the great majority of QSOs have very low (but significant) intrinsic optical polarization (Stockman, Moore, and Angel 1982). The distribution of polarization is dominated by QSOs with $P < 1.5\%$ ($\bar{P} \sim 0.6\%$). Among these low polarization ("normal") QSOs, there are no significant polarimetric differences between radio-loud and radio-quiet QSOs.

A small fraction of QSOs exhibit distinctly higher polarization ($P \sim 4$-20%). Essentially no QSOs have intermediate polarizations ($2\% < P < 4\%$). The discontinuity in the distribution of polarization suggests that there are two basic types of QSOs - the normal QSOs and the highly polarized QSOs (HPQs).

The variability and wavelength dependence of polarization provide further evidence for a distinction between HPQs and normal QSOs. HPQs exhibit strong variability on time scales of days and only slight wavelength dependence (Moore and Stockman 1981). In contrast, the polarization of normal QSOs is only weakly variable on time scales of years and exhibits significant wavelength dependence (Stockman, Moore, and Angel 1982).

D. S. Heeschen and C. M. Wade (eds.), Extragalactic Radio Sources, 341–344.

https://doi.org/10.1017/S0074180900028102 Published online by Cambridge University Press

II. CORRELATIONS BETWEEN POLARIZATION AND OTHER QSO PROPERTIES

The objectives of our survey are not only to define the polarimetric properties of QSOs, but also to systematically examine the correlations between high polarization and other properties. Previous analyses of the properties of the HPQs have been limited by the fact that only four examples were known. There is now a large sample of HPQs (27 known) available for examining correlations. Details of this discussion will be presented by Moore and Stockman (1982).

Our results confirm previously suspected correlations (e.g. Visvanathan 1973) between high polarization, strong rapid photometric variability, and steep optical continua. We would note that the optical/infrared continua are not only steeper, but also better approximate a straight power law than do the continua of normal QSOs. A possible correlation is that the HPQs may have a higher ratio of X-ray to optical luminosity than normal QSOs (both radio-loud and -quiet).

An important aspect of the HPQs is their radio properties (Moore and Stockman 1981). With one exception, all of the HPQs are radio-loud QSOs. Only one of 50 ($2 \pm 2\%$) optically-selected QSOs in our survey has $P > 2\%$, this compares with 26 HPQs among 181 radio-selected QSOs surveyed ($14.4 \pm 2.8\%$). The difference is statistically significant. Also, the one radio-quiet HPQ (PHL 5200) is an atypical HPQ in nearly every respect (for example, it is not variable); the origin of its high polarization ($P \sim 4\%$) is probably different from that of other HPQs. The occurence of (variable) high polarization is the one polarimetric distinction we have found between radio-loud and radio-quiet QSOs.

The radio-loud HPQs are nearly all compact, flat spectrum variable radio sources (see Moore and Stockman 1981). The HPQs also frequently exhibit extreme radio properties such as superluminal motion and low-frequency variability. Two of the four known superluminal sources, 3C 279 and 345, are HPQs. Also, of seven definite HPQs which have been monitored at low radio frequencies, five have exhibited variability.

The general picture of the HPQs as a class is, thus far, that they are very similar to BL Lac objects. However, analysis of our survey results shows that the HPQs also share some properties with normal QSOs. There are no apparent correlations between high polarization and redshift, optical luminosity, and emission line equivalent width. These null correlations have direct implications for the theoretical model discussed below.

III. THEORETICAL IMPLICATIONS

There are several models which address the relationship between normal QSOs and HPQs. For brevity, we consider here the implications of our results for only the relativistic beaming model (e.g. Blandford and Rees 1978, Scheuer and Readhead 1979).

https://doi.org/10.1017/S0074180900028102 Published online by Cambridge University Press

In general, the beaming model provides a straightforward explanation of many of our results. In this model, normal QSOs and HPQs have the same fundamental structure; however, the observer's orientation with respect to the anisotropic jet emission determines whether a QSO is observed as a normal QSO or an HPQ. The emission characteristics of the HPQs define the properties of the jet emission, while the characteristics of normal QSOs represent the properties of the isotropic emission. This model naturally accounts for the fact that essentially all HPQs are compact radio sources. Relativistic beaming eases theoretical difficulties imposed by the rapid variability and high luminosity of HPQs (both at radio and optical frequencies); beaming can also account for superluminal expansion.

However, there are two important predictions of this theory which are not supported by our results. In the HPQs, we are viewing both the jet emission (variable, highly-polarized, steep continuum) and the isotropic component (emission lines, low polarization, hard continuum). This implies that the HPQs should be systematically more luminous and should exhibit weaker (lower equivalent width) emission lines. Our correlation analyses do not confirm these predictions. Because the HPQs and normal QSOs have similar luminosities and emission line strengths, one must conclude (in this model) that the anisotropic component contributes a small fraction of the continuum. However, other characteristics of the HPQs (e.g. the smoothness of the energy distribution, the lack of polarimetric wavelength dependence, and the amplitude of variability) argue that the anisotropic component dominates the optical/infrared continuum.

While the relativistic beaming model is very attractive for explaining our results, it is not clear how to resolve the apparent contradiction described above. Perhaps the isotropic continuum (but not the emission lines) is suppressed in the HPQs. A program of spectropolarimetric monitoring of the HPQs during bright and faint phases would provide an excellent test of whether there are two components present.

REFERENCES

Blandford, R.D., and Rees, M.J. 1978, Pittsburgh Conference on BL Lac Objects, ed. A.M. Wolfe, p. 328 (Pittsburgh: University of Pittsburgh).
Moore, R.L. and Stockman, H.S., 1981, Ap. J., 243, 60.
Moore, R.L. and Stockman, H.S., 1982, in preparation.
Scheuer, P.A. G., and Readhead, A.C.S., 1979, Nature, 277, 182.
Stockman, H.S., Moore, R.L., and Angel, J.R.P., 1982, in preparation.
Visvanathan, N. 1973, Ap. J., 179, 1.

DISCUSSION

REES: How does 3C 273 (a superluminal radio source) fit in to your classification scheme?

MOORE: 3C 273 is superluminal, but is a low polarization QSO. This could still fit into the beaming model if, for example, the opening angle of the optical beam were smaller than the radio beam. There are other possible explanations, but not a clear answer.

WILSON: PHL 5200 in which you find high polarization, has broad optical absorption lines, presumably intrinsic to the QSO. Is there any correlation between the polarization and the presence of such absorption lines?

MOORE: We have surveyed a sample of other absorption-trough QSOs like PHL 5200 and all of them have low polarization.

MARSCHER: I have two comments. First, the flux which is responsible for ionization and hence for the luminosity of emission lines, comes from the far ultraviolet. Optical continuum observations generally tell you little about the presence or absence of an isotropic, flat-spectrum, non-varible component dominant in the far UV, so that we should not discard relativistically beamed models on the basis of strong emission lines. Also, 3C 446 looks like a BL Lac object when it's bright, and a quasar when weak. Hence, inclusion of the (unknown) fraction of BL Lac's which are in fact quasars with weak broad lines swamped by the continuum, might give HPQs weaker mean emission lines than other QSOs.

MOORE: I would not discard relativistically beamed models on the basis of strong emission lines in HPQs; there is a good deal of other evidence which supports this type of model. However, the prediction that the presence of the anisotropic optical continuum should systematically decrease the emission line equivalent widths (and increase the optical luminosities) of HPQs is based on the assumption that the isotropic emission (e.g., the optical/far-UV flux ratio) is similar among HPQs and normal QSOs. The results do require refinement of this simplifying assumption in the beaming models.

It is true that distinguishing HPQs and BL Lac objects is not straightforward without good spectroscopic observations over a range of brightness. I would like to see more monitoring of HPQs and BL Lac objects, particularly at faint phases. It is my opinion that the selection effect you mention, while present, does not strongly influence the results.