A SPECTROSCOPIC SEARCH FOR GALAXIES ASSOCIATED WITH QUASI-STELLAR OBJECTS*

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It is generally assumed that quasi-stellar objects represent phenomena taking place in galaxies. There are at least three lines of reasoning that lead to this viewpoint. First, there appears to be a continuity of properties extending from Seyfert galaxies and N systems to QSOs with the differences between the various groups principally a question of the contrast between the luminous central object and its surrounding galaxy. Since Seyfert galaxies and N systems are definitely in galaxies, it is concluded that QSOs must also be in galaxies which are not directly visible because of the high luminosity of the central object. A second argument is based on the result that QSOs do not appear to differ dramatically in abundances of elements from those which are typical of normal galaxies. With the prevailing view that virtually all the elements heavier than helium originated as a result of stellar processes, it would be concluded that QSOs must be associated with galaxies of stars that produced the heavier elements. A third, rather indirect argument is based on the results of Stockton (see his paper in this volume) and others that QSOs are often found in groups of galaxies and therefore are likely to be located in galaxies themselves (guilt by association). But the fact is that direct evidence that QSOs are in galaxies is sadly lacking.

A few QSOs show some kind of very faint nebulosity associated with them. However careful studies of objects such as 3C 48 (Wampler et al. 1975), 3C 249.1 (Richstone and Oke 1977) as well observations of the jet in 3C 273 indicate that the extended emission in these objects results from gaseous emission or other nonstellar processes. It should also be pointed out that there is little spectral data available in the literature pertaining to the stellar component of N galaxies.

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To pursue these matters further, we have been carying out an extended series of spectroscopic observations of active extragalactic objects. The goal has been to detect the spectra of the stars of associated galaxies, and where detected, to estimate the brightness of the galaxies. Portions of the results, those concerning BL Lacertae objects, have already been published (Miller, et al. 1978a; and earlier references given in that paper), and a thorough review of all results covering BL Lac objects, N systems and QSOs is in preparation (Miller 1980; based on review given at June 1979 meeting of Astronomical Society of the Pacific), so this account will be brief and limited principally to the results on QSOs.

All observations were made with the Lick Observatory Shane 3 m reflector equipped with the image-tube scanner (Miller, et al. 1976); details of the observations will be given elsewhere (Miller 1980). The general approach was to obtain very high signal-to-noise data by observing each QSO on several nights and at different grating tilts to minimize the possibility of system response irregularities appearing in the reduced data even at a very low level. In addition, the independent spectra obtained from the two entrance apertures were kept separate in the averaging of results from different nights, so that two independent spectra of equal observing time were ultimately obtained for each object (see Miller and Hawley 1977 for an illustration of the approach used). All observations were made with a rectangular entrance aperture 2".4 x 4".0, since the annular aperture used in another study (Miller, French, and Hawley 1978b) is of no use for essentially stellar appearing objects. As a supplement and check on the approach, observations identical in approach were made of a number of N galaxies, where detection of the stellar features of a galaxy was to be expected.

The type of galaxy to be expected in association with QSOs is of course an open question. Seyfert galaxies tend to be found in spirals, while N systems are often in ellipticals. If the galaxies associated with QSO were dominated in stellar light by stars of A type or earlier, the stellar component would be very difficult to detect spectroscopically because of the complete correspondence of strong emission features of the QSO with strong absorption features of the stellar component. Since galaxies with strong radio sources are generally ellipticals, it might be expected that QSOs which are radio-loud would also be located in E galaxies. The late-type stars of an E galaxy produce an absorption spectrum that has features which occur in regions free of strong QSO emission. In particular, the Mg I feature near 5175 Å is one of the strongest features in the spectra of galaxies. Strong absorption is also observed at Ca II H and K and Na D, but since these features can be produced by gas as well as stars, they are not as good an indicator of the stellar component as is Mg I. The continuum of E galaxies is also heavily inflected, with a sharp break in the continuum shortward of 4000 Å. On an F_λ scale the continuum is approximately level from 4000 to 4300 Å, beyond which the

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continuum rises considerably to about 4800 Å, where it levels out once again because of Mg H absorption. Just beyond Mg I, it abruptly rises up again. For a more detailed discussion of these characteristics, see Miller (1980).

Given the above considerations, this study was limited to detecting E galaxies, and the majority of the objects selected were radio-loud QSOs. The QSOs were selected for low luminosity, that is, for being within 2 mag.of the Hubble line for first-ranked giant E's. In all, 9 QSOs and 9 N systems comprise the sample for this study. The overall results are straightforward to summarize: the diluted stellar spectral features of a galaxy were detected for 7 of the N systems, but for none of the QSOs. If galaxies comparable in type and brightness to those detected for the N systems were associated with QSOs, they would have also been detected given the quality of the data. Furthermore, the N galaxies detected have magnitudes inferred from the strengths of the spectral features observed that places them generally 1-2 mag. fainter than a first-ranked giant E. This implies that whatever may be the type of galaxies associated with the QSOs in this study, they are certainly not first-ranked giant E's; if they are E galaxies at all, they are at least 1-2 mag. fainter then first-ranked ones. The table below summarizes the results for the QSOs. Limits given are based on using the Sandage (1972) curve of growth for E galaxies to extrapolate the value derived for the aperture used to his standard metric diameter. Also we adopted $H_o = 75$ km s^{-1} Mpc^{-1} and $q_o = 1$; in this system a first-ranked giant E is -22.4 V mag. For 3C 215 and 1635+119, an extremely weak feature was seen in the data near Mg I, but it is quite likely that feature was not real. For more details on these results and those on N systems, see Miller (1980).

QSOs

Object	3C 47	PHL 1093	0736+01	3C 215	1217+02
Z	0.42	0.26	0.19	0.41	0.24
M_v(galaxy)	>-22.9	>-21.1	>-21.0	$\gtrsim$-21.1	>-20.8

Object	3C 277.1	B264	3C 323.1	1635+119
Z	0.32	0.10	0.26	0.15
M_v(galaxy)	>-19.9	>-19.1	>-21.7	$\gtrsim$-20.6

The principal result of this study, that QSOs in this sample are not located in first-ranked giant E galaxies, or even in E galaxies comparable in luminosity to those detected in N systems, raises a number of questions. Are these QSOs in galaxies at all? They could be spirals, but then one would have to acknowledge spiral galaxies can produce strong radio sources. Since BL Lac objects and N systems, active extragalactic objects that are radio-loud, are generally found to be in E galaxies when the galaxies can be detected, it is reasonable to assume that at least the radio-loud QSOs in this study are in E galaxies also. It is important to consider whether these results could be a result of the definition of QSOs. Since the QSOs were selected for low luminosity and for not being called N systems, this selection process would directly eliminate those QSOs with very luminous galaxies: the galaxies would be visible and they would have been classified as N galaxies. This would imply that the principal difference between the N galaxies and the QSOs in this study would be the brightness and hence visibility of the galaxy. However, preliminary analyses of the spectra of the two groups suggests that, for the most part, N galaxies and QSOs can be distinguished by spectroscopic characteristics alone. For N systems the lines appear stronger relative to the continuum, and the rise in the continuum shortward of 4000 Å, commonly seen in QSOs, is rarely seen in N systems; a more detailed and quantitative discussion of these matters will be presented elsewhere (Miller 1980).

To conclude, it is clear what kind of galaxies these QSOs are not in, but whether they are in galaxies at all and what type remains for future work.

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DISCUSSION

P. Veron: What are the main differences between the spectra of the N-galaxies and of the QSOs?

Miller: The analysis of the line spectra of the two groups of objects is still in a preliminary stage. It appears that forbidden lines of [OII] and [OIII] have much larger equivalent widths in the N systems than in the QSOs in our sample. Also, only one N galaxy shows the increase in "continuum flux" toward the Balmer limit which is observed in nearly all the QSOs in the sample.

Arp: You said you compared BL Lac to a giant E galaxy, but you actually showed it compared to M32. Does that mean the spectrum is a better match to a dwarf elliptical?

Miller: The strengths of absorption features seen in normal elliptical galaxies are functions of both the absolute magnitudes of the galaxies and the radial distance from the center of the observed regions. The BL Lac observations were made with an annular aperture which corresponds to a distance interval of 6 to 10 Kpc when projected on BL Lac. Data in the literature indicate that the spectrum of the nucleus of M32 should provide a reasonable match for the much more luminous BL Lac galaxy in the outer regions which we observed, and this was borne out by the observations.

Wehinger: What size apertures did you use? Were the apertures annular like the ones used to observe the BL Lac objects?

Deep ESO 3.6-m prime-focus IIIa-F plates show extended structure (in the form of log intensity profiles) in the range ~ 2 to 5 arc sec from the QSO, at surface brightness of ~ 10 to 20% night sky (at best). Extended asymmetric structures have integrated apparent magnitudes of $\gtrsim$ 22 to 23 for quasars in the range z = 0.2 to 0.5. This work was done in collaboration with Sue Wyckoff (ASU) and Tom Gehren (MPIA).

Miller: The QSOs were typically observed with apertures of rectangular sizes of about 2$''$.5 x 4$''$.0. The annular apertures had inner and outer diameters of 6" and 10", respectively. The faint features you report near QSOs are too faint to be observable with our equipment on Mt. Hamilton.

Grandi: I would like to emphasize that Seyfert 1 spectra do show the continuum rise to the ultraviolet that is seen in QSOs but not, in general, in N galaxies. Thus, there exist objects inside galaxies with spectra equivalent to QSOs.

Miller: The spectra of Seyfert 1 galaxies is indeed very similar in this respect to those observed in QSOs.