QUASARS AROUND THE SEYFERT GALAXY NGC 3516
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ABSTRACT

We report redshift measurements of five X-ray–emitting blue stellar objects located less than 12' from the X-ray Seyfert galaxy NGC 3516. We find these quasars to be distributed along the minor axis of the galaxy and to show a very good correlation between their redshift and their angular distance from NGC 3516. Moreover, the redshifts of these five quasars are 0.33, 0.69, 0.93, 1.40, and 2.10, which are very near the peaks of the redshift periodicity distribution (i.e., $z = 0.3, 0.6, 0.96, 1.41,$ and 1.96). All these observed properties strikingly confirm, around this single example of a Seyfert, the composite picture derived from previous physical associations of quasars with low-redshift active galaxies.

Subject headings: galaxies: distances and redshifts — galaxies: Seyfert — quasars: general

1. INTRODUCTION

Recently Radecke (1997) has presented evidence that there is a significant (minimum of 7.4 $\sigma$) excess of bright X-ray sources around a nearly complete sample of Seyfert galaxies. Arp (1997a) had inspected each individual X-ray map of 24 Seyfert galaxies with an apparent magnitude between 8.04 mag $\leq B_{V} \leq$ 12.90 mag and found that, on Schmidt Survey plates, most of these excess X-ray sources are identified with blue stellar objects (BSOs). These X-ray–emitting BSOs generally show pairing and alignment configurations across the central Seyfert galaxies.

We have started a program to obtain the optical spectra of these X-ray–emitting BSOs. Herewith we present our results in the field NGC 3516. NGC 3516 is a strong X-ray Seyfert galaxy with apparent magnitude $V = 12.40$ and redshift $z = 0.009$. In Radecke's (1997) Seyfert sample, NGC 3516 belongs to the faintest and most distant category. X-ray sources associated with this galaxy would therefore be as bright as $6 \times 10^{40}$ ergs s$^{-1}$, which is about 300 times brighter than any Galactic X-ray source. There are five BSOs listed in Table 3 of Arp's (1997a) paper; these objects are located in the region $\theta < 12'$ and aligned northwest-southeast across NGC 3516. (see Fig. 1, in which these BSOs are identified by their X-ray count rate [$C = $ countsks$^{-1}$] value).

We obtained the spectra of the five BSOs on 1997 April 4–5 using the 2.16 m telescope at Xinlong Station, Beijing Astronomical Observatory. An OMR spectrograph was attached at the Cassegrain focus. A TEK 1024 $\times$ 1024 CCD served as detector at a resolution of 400 Å mm$^{-1}$. The coverage of the spectra was from 3700 to 8000 Å. Integration time for each spectrum was 3600 s. An FeAr lamp was used for wavelength calibration, and Feige 34 and Hz 44 were used as flux standard stars. The data were reduced with the IRAF package. One of the objects, Q1107 + 7232 ($C = 7.1$), is already listed in the Hewitt-Burbidge (1993) quasar catalog. It has a redshift of $z = 2.10$. We found the other four objects all to be quasars. Their redshifts are listed in Table 1.

We would like to thank E. Margaret Burbidge for allowing us to quote her measures with the 3 m reflector at Lick Observatory. For the last two quasars in Table 1, she reports independently measured redshift values of $z = 0.68$ and 0.33 (E. M. Burbidge 1997, private communication).

2. DECREASING REDSHIFT AS THE QUASARS INCREASE THEIR DISTANCE FROM THE GALAXY

It is of interest to note that for these five quasars we found very good linear correlation between redshift $z$ and $\theta$, the angular distance from the center of NGC 3516. The statistical analyses show that the linear regression is $z = 3.06-0.22\theta$, with the correlation coefficient $-0.957$ and the standard error of the regression line ($S_{y|x}$) 0.23. We note also that, along the northwest-southeast alignment of these quasars, at $\theta \sim 22.5$ there is a very strong X-ray source that is listed as having a Seyfert spectrum (Véron-Cetty & Véron 1996) with redshift $z = 0.089$ (about 10 times the redshift of NGC 3516). Optically it is a compact, semistellar object. With its strong X-ray and radio properties, it is closely allied to BL Lac objects and therefore to the transition between quasars and objects with increasing components of stellar populations. When we consider these objects together, in Figure 2, we plot redshift $z$ against the natural logarithm of $\theta$ and find that there is a good correlation: $z = 3.86-1.28 \ln \theta$. The correlation coefficient is $-0.942$, and the standard error of the regression line is 0.276. If these quasars were ejected from the central galaxy, it means that the younger the quasar, the closer it is to the center and the higher the redshift (see Table 2).

3. ALIGNMENT ALONG GALAXY MINOR AXIS

It is shown in Figure 3 that these five quasars and the X-ray Seyfert galaxy in the center of the field lie within $\pm 20'$ of a line that is the minor axis of NGC 3516. Just the
chance that the above six objects could accidentally lie within ±20° of a line through the center of the galaxy is, by itself, only 10⁻⁴. But it is now becoming clear that Seyfert galaxies eject quasars preferentially along their minor axes (see Arp 1997b, 1998), and the NGC 3516 quasars turn out to lie within a few degrees of its minor axis. Therefore, the chance of accidental occurrence is about another 2 orders of magnitude less.

4. QUANTIZATION OF REDSHIFTS

An especially significant result for these six objects is their specific redshift values. It has been known for a long time

\[
\begin{array}{cccc}
\text{Quasar} & \text{Line} & \lambda_{\text{line}} (\text{Å}) & z \\
\hline
Q1105 + 7242 (C = 4.4) & \text{C m } \lambda 1909 & 3658 & 0.916 \\
& \text{Mg } \text{II } \lambda 2798 & 5428 & 0.940 \\
& \text{H} \gamma \lambda 4340 & 8391 & 0.932 \\
& (\text{mean } z = 0.929) & \\
Q1105 + 7238 (C = 3.1) & \text{C iv } \lambda 1549 & 3727 & 1.406 \\
& \text{C m } \lambda 1909 & 4569 & 1.393 \\
& \text{Mg } \text{II } \lambda 2798 & 6706 & 1.397 \\
& (\text{mean } z = 1.399) & \\
Q1106 + 7244 (C = 6.6N) & \text{Mg } \text{II } \lambda 2798 & 4729 & 0.690 \\
& \text{H} \delta \lambda 4102 & 6944 & 0.693 \\
& \text{H} \gamma \lambda 4340 & 7324 & 0.688 \\
& \text{H} \beta \lambda 4861 & 8210 & 0.689 \\
& (\text{mean } z = 0.690) & \\
Q1108 + 7226 (C = 6.6S) & \text{Mg } \text{II } \lambda 2798 & 3702 & 0.323 \\
& \text{H} \beta \lambda 4861 & 6468 & 0.330 \\
& [\text{O } \text{iii} ] \lambda 5007 & 6659 & 0.329 \\
& \text{H} \alpha \lambda 6563 & 8734 & 0.331 \\
& (\text{mean } z = 0.328) & \\
\end{array}
\]

\[
\begin{array}{ccc}
\text{Object} & \text{Redshift } z & \text{Distance } \theta \text{ from Galaxy } (\text{arcmin}) \\
\hline
Q1107 + 7232 & 2.1 & 4.34 \\
Q1105 + 7238 & 1.4 & 7.42 \\
Q1105 + 7242 & 0.93 & 10.99 \\
Q1106 + 7244 & 0.69 & 10.37 \\
Q1108 + 7226 & 0.33 & 11.23 \\
\end{array}
\]
TABLE 3

| Quasar     | Redshift | Formula Peak |
|------------|----------|--------------|
| S1102 + 7246 ...... | 0.09     | 0.06         |
| Q1108 + 7226 ...... | 0.33     | 0.30         |
| Q1106 + 7244 ...... | 0.69     | 0.60         |
| Q1105 + 7242 ...... | 0.93     | 0.96         |
| Q1105 + 7238 ...... | 1.40     | 1.41         |
| Q1107 + 7232 ...... | 2.10     | 1.96         |

that the redshifts of quasars have preferred values at \( z = 0.06, 0.30, 0.60, 0.96, 1.41, \) and 1.96, and that these redshift peaks fit the formula \( \Delta \ln (1+z) = 0.206. \)

The fit to the formula is given by Karlsson (1977). Some claims that the periodicity was a selection effect of redshifting emission lines through \( UBV \) filters have been refuted by showing that the effect is not large enough to be significant and, more directly, by finding the same strong periodicity in quasars that had been identified from their radio emission (Arp et al. 1990). It has also been shown that modern detectors give full wavelength coverage of the spectra without gaps (Burbidge 1978). And, of course, the present measures in NGC 3516 represent a complete sample of the brightest candidates that have been selected by X-rays.

As was pointed out by Zhu & Chu (1990), this periodicity in redshift is clearer for multiple quasars, which are associated with low-redshift galaxies. In Table 3 we find that the five aligned quasars plus the quasar-like Seyfert galaxy have redshift values very close to these peaks. Considering that quasars in general usually define broader peaks, the quasars in this field are a particularly strong confirmation of this property, which is so difficult to interpret as a Doppler-induced redshift.

5. SUMMARY

All of the properties of the high-redshift X-ray objects in the NGC 3516 field confirm the body of earlier results on quasars associated with active galaxies. We conclude that, because of the number of objects in this one group, the evidence has been greatly strengthened for quasars being ejected from nearby active galaxies and exhibiting intrinsic redshifts.

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