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LETTERS

A companion quasar to 3C345

Bruce Margon*, Gary A. Chanan† & Ronald A. Downes‡

*Department of Astronomy, University of Washington, Seattle, Washington 98195, USA
†Columbia Astrophysics Laboratory, Columbia University, New York, New York 10027, USA
‡Department of Astronomy, University of California, Los Angeles, California 90024, USA

Although some quasistellar objects (QSOs) are known to be members of small groups of galaxies (see refs 1–3), there is no known case of a QSO in a rich cluster of galaxies[4]. Whether this has important implications for the nature of QSOs, or is simply a reflection of the difficulty of observing high-redshift clusters, is unclear. Here we report the discovery of a new QSO which provides perhaps the strongest evidence to date for quasar membership in a rich cluster.

The QSO was discovered during a programme aimed at the identification of optical counterparts of X-ray sources observed serendipitously by the Einstein Observatory. The detector used, the imaging proportional counter[5], yields positional accuracies of the order of 1 arc min, typically restricting optical candidates for the X-ray source to only a few objects. These candidates were then each examined spectroscopically. So far we have identified more than 40 previously uncatalogued QSOs using this technique, and preliminary results on the objects as a class are reported elsewhere[6]. During X-ray observations of quasar 3C345, a serendipitous X-ray source located 8 arc min north-east of the quasar was discovered, in addition to emission from 3C345 itself. The observed flux from the new source is 3.2×10^{-13} erg cm^{-2} s^{-1} in the 0.5–4.5-keV band. This flux, which is roughly 7% of that observed from 3C345 (ref. 7), is typical of the serendipitous sources in our sample. Three separate observations during a 6-month period in 1979–80 showed no evidence for intensity variability of the new source in excess of the $\pm 20\%$ statistical uncertainty in the count rate. There was also no evidence for X-ray variability in 3C345 during this period.

Spectroscopic observations of optical candidates in the X-ray field were obtained on 16 May 1980, using the Robinson-Wampler image tube scanner[8] at the Lick Observatory 3-m Shane reflector; the grating yields 20 Å spectral resolution in the 3,500–8,500 Å range. The X-ray source was readily identified with a previously unreported faint QSO, which we designate 1641+3998. The coordinates of the object are $\alpha(1950) = 16$ h 41 min 54.1 s, $\delta = +39°59'17''$. Based on calibrations of the image diameter of the object on the Palomar Observatory Sky Survey[9], we estimate the magnitude of the object at the epoch of those plates as $B = 18.7\pm 0.5$. Both the Sky Survey and our spectrophotometry show the QSO to be quite blue. As stressed in ref. 6, the probability of a chance coincidence of a random QSO with the X-ray source is negligible, so the identification of the quasar with the source is secure. The finding chart for the object in Fig. 1 is reproduced from a 4-m Mayall telescope plate obtained in 1973; also shown is 3C345.

The spectrum of the newly discovered QSO is of particular interest, and is shown in Fig. 2. Despite the modest signal-to-noise ratio, four strong emission lines are clearly visible at $\lambda\lambda$ 4,450, 6,912, 7,750, and 7,980 Å. We identify these features as Mg II λ 2,800, Hγ, Hβ and [O III]λ 5,007, respectively, and derive a galactocentric redshift $z = 0.594\pm 0.001$, where the uncertainty is dominated by the breadths of the permitted emission lines. The galactocentric redshift of 3C345 (see refs 10, 11) is $z = 0.595$, where again we estimate a formal uncertainty of at least ± 0.001 due to emission line widths. Thus to within the measurement errors, the redshifts of these two quasars are identical. The spectra of the objects are at least superficially similar in appearance, although this is perhaps not surprising in view of the limited variety in the emission lines which are typically seen in QSOs at this redshift.

We may estimate the probability that the remarkable redshift agreement of the two objects is a chance coincidence of two randomly distributed, unrelated QSOs. Our X-ray observations[6] yield 0.6 serendipitous sources per square degree, and we identify about half of these as QSOs with $z \lesssim 1$. Thus we expect to observe $\approx 6\times 10^4$ QSOs before finding one with a

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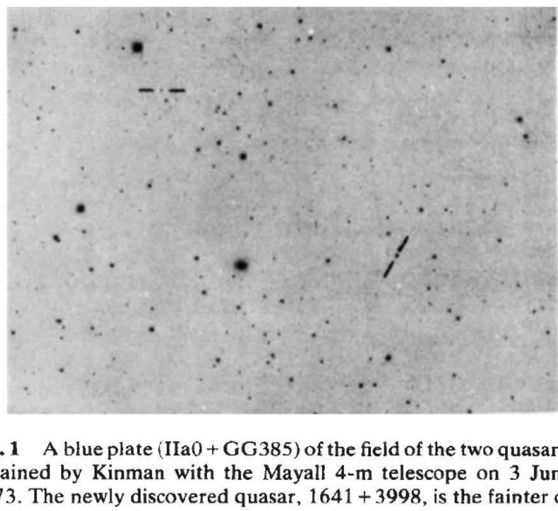

Fig. 1 A blue plate (IIa0 + GG385) of the field of the two quasars, obtained by Kinman with the Mayall 4-m telescope on 3 June 1973. The newly discovered quasar, 1641+3998, is the fainter of the two flagged objects, near the north-east of the field; 3C345 is the brighter object marked 8 arc min to the south-west.

'companion' as close in position (0.06 deg^2) and redshift (10^{-3}) as the current example is to 3C345. In fact only about 100 QSOs had been observed[7] when 1641+3998 was discovered, so the probability of a chance coincidence is ~0.002. Therefore, tempered by the hazards of *a posteriori* probability calculations, we conclude that the association of 3C345 and 1641+3998 is statistically significant and unlikely to be accidental.

If we accept the physical association of our two quasars, the explanations for such a situation are limited. We have briefly considered the extraordinary possibility that 1641+3998 could be a gravitationally focused image of 3C345, similar to the two currently known examples of this effect[12,13]. The very large angular separation of the images compared with the previous cases would imply an unusual mass and/or mass distribution for the focusing matter. Remarkably this situation cannot be immediately dismissed, as a cluster of galaxies at $z = 0.01$ with mass $2 \times 10^{14}\ M_\odot$ could create such an image. However, such a cluster must have a very extreme mass-to-luminosity ratio to avoid obvious detection. A more awkward difficulty with this hypothesis is that the ratio of fluxes of the two QSOs should be independent of wavelength. Although the optical and X-ray flux ratios of the two objects do agree well (within 3 orders of magnitude), 3C345 is an intense radio source (11 Jy at 178 MHz) leading to the prediction of an easily detectable radio flux from 1641+3998, barring long differential time delays. Maps which subtract the side lobes of 3C345 (ref. 14) do not show such a source, to limits of 10 mJy. The agreement of the ratio of optical and X-ray fluxes is thus probably simply a manifestation of the relative constancy of this parameter previously noted in large samples of radio-selected[15] as well as X-ray selected[6] QSOs.

The alternative hypothesis, which we favour, is that the redshift agreement of these two QSOs indicates their common membership in a cluster of galaxies. The projected separation of several Mpc would then indicate this to be a rich cluster, the first such example of a cluster with QSOs. Although theoretical calculations of cluster diameter evolution with redshift[16] indicate that distant rich clusters should be smaller than at the current epoch, this poses no difficulty in the present case as these evolutionary effects become noticeable only at larger redshift. As the velocity dispersion in rich clusters of galaxies is as large as 1,500 km s^{-1}, one might worry that the observed small limit on the velocity difference between 3C345 and 1641+3998 ($\lesssim 300$ km s^{-1}) implies a cluster velocity dispersion grossly inconsistent with this norm. However, this proves not to be the case. If for simplicity, the radial velocities of the cluster galaxies are assumed to have a gaussian distribution, then we can convert the observed difference between two members into 90% confidence limits on the actual dispersion. A 300 km s^{-1} difference between two cluster members implies a cluster dispersion in the range 100–3,000 km s^{-1} (90% confidence). Thus, perhaps surprisingly, the small observed velocity difference is not an awkward constraint on this model. The virial mass implied for the cluster by this allowed range of dispersions is in the range $10^{13.5}$–$10^{16.5} M_\odot$, again, not restrictive, but consistent with the parameters of known rich clusters.

Our failure to detect X-ray emission from this putative cluster is not necessarily surprising, but means that the cluster has an X-ray luminosity less than about half that of the Coma cluster (the X-ray bright core of which would appear point-like at this distance). However, Einstein observations (F. Abramopoulos, personal communication) indicate this is not unusual even for rich clusters. In addition, if 3C345 lies close to the centre of the cluster, then the possibility of source confusion implies that the cluster will be even more difficult to detect in X rays.

Our hypothesis can be tested in that the normal galaxies in this putative cluster are expected to appear at $V = 22$–23 and thus be directly observable. Good quality 4-m plates of the field obtained by Kinman do show numerous faint galaxies nearby. However, the space density of clusters at this faint apparent magnitude is large enough that two or three such clusters are expected on every high latitude 4-m plate[17]. Thus the probability of a chance superposition of a faint, unrelated cluster on this pair of QSOs is not negligible, and radial velocities of the galaxies will be necessary to verify the proposed association.

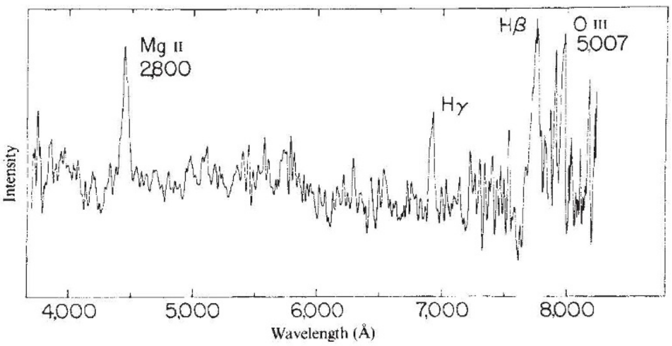

Fig. 2 The spectrum of the quasar 1641+3998, obtained with the Lick 3-m Shane reflector, with 20-Å spectral resolution. The data have been converted to relative fluxes above the atmosphere through observation of spectrophotometric standard stars, and the most prominent emission features are identified.

Attention has recently been drawn to other close groupings of QSOs with similar redshifts[18-22], and diverse interpretations involving clusters, superclusters and non-cosmological redshifts have been advanced. Whether these pairs, including the one discussed here, represent clusters or superclusters is of secondary importance to the broader conclusion that QSOs exhibit similar clustering characteristics as galaxies. The pair discussed here, being at low redshift, should be suitable for future research.

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Random alignment of quasars

M. G. Edmunds & G. H. George

Department of Applied Mathematics and Astronomy, University College, PO Box 78, Cardiff CF1 1XL, UK

Arp and Hazard[1] have reported several peculiar alignments of quasars, alignments which are exact to the limit of resolution on a Schmidt plate (2 arc s). We report here our investigation of the claim that the probability of such alignments occurring purely by chance is exceedingly small. Because the correct statistical analysis is not immediately obvious, we have performed a series of computer experiments to investigate how often such alignments will occur by chance.

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