A&A 414, L37–L40 (2004)
DOI: 10.1051/0004-6361:20031745

Astronomy
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Astrophysics

The double radio source 3C 343.1: A galaxy-QSO pair with very different redshifts

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Received 20 October 2003 / Accepted 16 December 2003

Abstract. The strong radio source 3C 343.1 consists of a galaxy and a QSO separated by no more than about 0.25″. The chance of this being an accidental superposition is conservatively $\sim 1 \times 10^{-8}$. The $z = 0.344$ galaxy is connected to the $z = 0.750$ QSO by a radio bridge. The numerical relation between the two redshifts is that predicted from previous associations. This pair is an extreme example of many similar physical associations of QSOs and galaxies with very different redshifts.

Key words. galaxies: active – galaxies: individual: 3C 343.1 – quasars: general – radio continuum: general

1. Introduction

Over the years many cases of QSOs associated with active galaxies with much smaller redshifts have been discovered. The papers generally show evidence involving radio emitting QSOs and bright galaxies, X-ray-emitting QSOs and active galaxies, and pairs with optical, radio and X-ray connections (Burbidge et al. 1971; Pietsch et al. 1994; Burbidge 1995, 1997, 1999; Radecke 1997; Arp 1967, 1996, 1997, 1999, 2003; Arp et al. 1990, 2002).

Two of the most impressive recent examples are the X-ray QSOs lying very close to the nucleus of NGC 3628 (Arp et al. 2002) and the discovery of two QSOs in the optical bridge between NGC 7603 and its companion galaxy (López-Corredoira & Gutiérrez 2002).

It has also been shown that in many of the cases known, the redshifts of the QSOs (z_q) are related to the redshifts of the parent galaxies (z_g) by the relation:

$$(1 + z_\mathrm{q}) \;=\; (1 + z_\mathrm{g})(1 + z_\mathrm{i})(1 + z_\mathrm{d})$$

where z_i is an intrinsic redshift component, and z_d is a measure of the Doppler shift (either positive or negative) associated at least partly with the ejection speed of the QSO from the nucleus of the galaxy. It is now well established that intrinsic redshift components follow the law $\Delta \log(1 + z_\mathrm{i}) = 0.089$ with peaks at:

$$z_\mathrm{i} = 0.061, 0.30, 0.60, 0.96, 1.41, 1.96, 2.63 \text{ etc.}$$

(Karlsson 1971, 1973, 1977, 1990; Burbidge & Burbidge 1967; Arp et al. 1990; Burbidge & Napier 2001). For nearby bright galaxies from which most of the bright samples have been taken z_g is very small, and z_d is also quite small, so that $z_\mathrm{q} \simeq z_\mathrm{i}$.

In this paper we briefly describe the properties of yet another pair which is much closer in angular separation than most of the cases so far found.

2. 3C 343.1

2.1. Optical properties

This powerful radio source in the 3C catalogue was first identified and its redshift was measured by Spinrad et al. (1977). They detected a strong emission line which they identified as [OII] λ 3727 at a redshift $z = 0.750$. Thus it was classified as a high redshift radio galaxy (Spinrad et al. 1985).

This source is one of four high redshift radio galaxies investigated in modern times by Tran et al. (1998) with the Low Resolution Imaging Spectrograph (LRIS) on the Keck 10 m telescope. Tran et al. found that the central spectrum showed no higher ionization lines other than [OII] λ 3727 and [OIII] $\lambda\lambda$ 4959, 5007.

However they found that there is a second system present which gives rise to an absorption line spectrum with high-n Balmer lines in absorption together with [OII] λ 3727 and [OIII] $\lambda\lambda$ 4959, 5007 emission. The redshift of this system is $z = 0.344$. They also showed that [OII] λ 3727 emission at the lower redshift can be seen over about 5″, while the emission line [OII] λ 3727 at $z = 0.75$ extends only over the nuclear region. Thus they concluded that two separate objects are contributing to the observed spectrum, an underlying active galaxy and a high redshift QSO.

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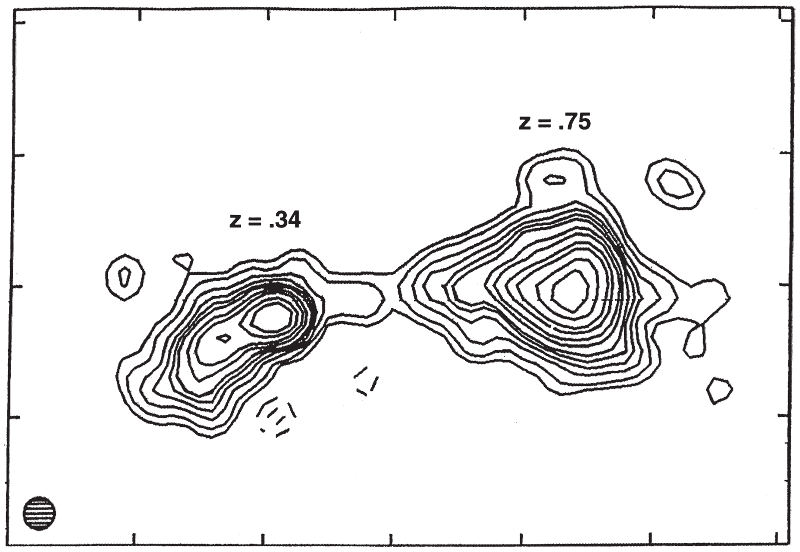

Fig. 1. Radio map at 1.6 GHz of 3C 343.1 by Fanti et al. (1985). (The tick marks are separated by 0.1″. The separation of sources is about 0.25″.) We assign the left hand (east) lobe to the galaxy with $z = 0.34$ and the right hand (west) lobe to the QSO with $z = 0.75$.

2.2. Radio properties

In Fig. 1 we reproduce the radio map of 3C 343.1 made by Fanti et al. (1985). The source was also mapped at 15 and 22.5 GHz by van Breugel et al. (1992). These maps show what is apparently a classical double-lobed radio source, where usually the galaxy responsible for the ejected radio emission lies between the two lobes. In 3C 343.1, however, we apparently have a radio galaxy emitting along one of its lobes a QSO that is itself a radio source, the two being of approximately equal intensity.

The relation of the radio emission isophotes to the optical isophotes is shown in images published by de Vries et al. (1997) where the Hubble Space Telescope imaging of a number of compact steep-spectrum sources is shown. Figure 2.26 of de Vries et al. shows, at the top, the HST/WFPC image of 3C 343.1. The optical radiation is double, aligned (as they measured it) 9° to the E-W direction, the eastern component being the brighter. Below it they show the radio image taken with VLBI at 0.6 GHz, and the image at the bottom of the figure shows the radio contours superposed on the HST optical image. The correspondence is exact, the radio contours fit right over the optical image. It is clear from these maps that the separation between the two centers is no more than about 0.25″.

2.3. Identification of components

We consider the HST image of de Vries et al. (1997), as shown by the top image in their Fig. 2.26. The western (fainter image) is clearly near the resolution of the F702W image of the WFPC2 of the Hubble Space Telescope, while the brighter, eastern component is clearly extended, more in the E-W than in the N-S direction. This corresponds to the extension of [OII] λ3727 emission over about 5″ which was detected in the lower redshift spectrum. Could the images be explained by a single optical structure with a superposed dust lane across the center? Their brief description gives no indication that this was considered a possibility. Moreover a dust lane while partially dimming the optical radiation in the middle panel of Fig. 2.26 can have no effect on the radio radiation. The radio emission as shown in the bottom panel of Fig. 2.26, with strong central contours in both E and W components, strongly suggests two separate radio emitters.

In summary, regardless of the exact pointing accuracy, there is no question that the HST has imaged the radio source 3C 343.1 The source is shown to consist of two optical objects. The Keck spectra show two separate spectra, one of $z = .34$ and one of $z = .75$. The redshifts can be assigned to the appropriate objects by their extension and compactness in the optical, spectroscopic and radio. But in fact this is only additional confirmation of the major point that there are two objects with strong evidence for physical association which have much different redshifts.

The optical compactness of the object at $z = .75$ would normally qualify it as a QSO. But it could also be called an AGN. Again the main result is the association of two much different redshifts.

3. Association between the two components

In the present case we know that the $z = 0.344$ object is a galaxy because it has narrow emission and absorption lines and is extended on the spectrogram of Tran et al. (1998). Moreover, the eastern component of the optical image (de Vries et al. 1997) is brighter and more extended than the western one, as on would expect a galaxy of that redshift to appear. The high resolution radio map galaxy with $z = 0.344$ clearly shows the classic bipolar radio ejection coming out in opposite directions from its center. As in many of the cases of ejections from galaxies, there is a QSO at the end of one or both jets (Burbidge 1995; Arp 1996; Arp et al. 2002; López-Corredoira & Gutiérrez 2002).

In the particular case of 3C 343.1 the accurate radio mapping of the European VLBI Network (Fanti et al. 1985) enables us to actually see what may be the compression of radio contours as bodies move through the ambient medium.

Figure 1 suggests that the QSO is moving away from the galaxy exactly along the line of the bridge joining them. The following material ejected from the galaxy in this direction, however, is apparently meeting the trail of QSO material and is compressed by that interaction.

This QSO-galaxy pair is unique because the separation between them is extremely small. Both components are seen together in the spectrum. The separation between the two centers is $0.25'' \simeq 2$ kpc while the angular size of the optical emitting region of the lower redshift galaxy is $\sim 5'' \simeq 40$ kpc ($H_0 = 60\ \mathrm{km\,s^{-1}\ Mpc^{-1}}$). With such a small separation it is possible that a radio bridge is being detected before it breaks up and the galaxy/QSO pair assume the configuration seen in other cases. It would be natural to expect the configuration to change rapidly at first with the radio bridge fading and breaking up as the objects separated. Such an evolution could explain the rather infrequent observation of radio bridges between galaxies and their ejecta.

4. The probabilities

In view of the fact that the 3C is a complete survey of bright radio sources in the northern hemisphere it is natural to calculate what are the chances of two of its sources accidently falling as close together as those pictured in Fig. 1.

If we say there are 300 radio galaxies in the catalogue, the total area of the sky within $0.25''$ is $\pi \times 25^2 \times 300 = 4.5 \times 10^{-6}$ sq deg. We place randomly one 3C quasar in the 23 000 sq deg of the Catalog down to DEC = $-5°$. The probability that it lies within $0.25''$ of any of these 300 radio sources is then $4.5 \times 10^{-6}/23\,000 = 2 \times 10^{-10}$.

There are 50 such 3C quasars so the probability that any lie within $0.25''$ is:

$$50 \times 2 \times 10^{-10} = 1 \times 10^{-8}.$$

But this is an overly conservative estimate for two reasons:

1) The radio plasma appears to form a continuous bridge between the galaxy and the quasar in Fig. 1. If that is accepted there would be no point in computing probabilities. But if we do not consider the radio material linking them to be a physical bridge, we must still estimate the chance that the radio tail from the galaxy accidentally points to within better than a few degrees to the quasar and similarly from the quasar back to the galaxy. This would give a further improbability of $(\pm 2/90)^2 = 5 \times 10^{-4}$. The combined probability of this configuration being chance is of the order of:

   $$5 \times 10^{-12}.$$

2) Further double spectra among the 300 may be present but unrecognized. There could well be other cases where there are fainter or unidentified lines as in the spectra of 3C 343.1, one of only four 3C quasars observed with Keck in Tran et al. (1998).

Additionally, there is abundant previous evidence for 3C quasars physically associated with bright active galaxies. In 1971 a paper usually referred to as B^2S^2 (Burbidge et al. 1971) investigated the QSO's in the 3C and 3CR Catalogs. They found that the probability of chance association with low redshift galaxies in this entire sample was $<10^{-3}$. This, however, was based solely on the criterion of nearness on the sky. In the subsequent years some of their closest pairs have shown other evidence for association and a number of additional high significance associations have been found (Arp 1996, 1998, 2003). If we ask the question what determines the probability of an association we can list five empirical criteria: nearness, alignment, centering, similarity of ejecta (usually z's or apparent mag) and connections (bridges, jets and filaments). In that case we can add at least 17 more associations of 3C quasars with low redshift galaxies having chance probabilities ranging from 10^{-3} to 10^{-9}. This seems to already take the case for physical association to a very high level of probability.

5. Redshift periodicities

The measured redshift of the QSO, $z = 0.750$, does not lie at one of the Karlsson peaks. However, if the galaxy has ejected the QSO, then its redshift should be calculated relative to the galaxy. Thus, going back to Eq. (1) and putting $z_\mathrm{q} = 0.750$, $z_\mathrm{g} = 0.344$ we find that

$$(1 + z_\mathrm{i}) = (1 + z_\mathrm{q})/(1 + z_\mathrm{g})(1 + z_\mathrm{d})] = 1 + 0.302$$

which is extremely close to the intrinsic redshift peak at $z_\mathrm{i} = 0.30$.

We do not know the value of z_d, but based on other pairs it has been shown that $|z_\mathrm{d}| \leq 0.04$ (Burbidge & Napier 2001). Thus the relationship between the observed and predicted values is very satisfactory. This adds further to the view that the pair is a true physical system.

6. Conclusion

We have discussed this pair of objects from the standpoint of whether there could be any "a posteriori quality" to their extraordinarily small probability of being an accidental configuration. In fact we have found that this pair has properties very similar, but more extreme than most of the other associations of QSOs and galaxies which have been discovered earlier – properties of nearness, alignment, disturbances, connections. Since there are very few cases that have been examined this closely, the possibility is raised that there are more such associations to be discovered.

Acknowledgements. We are grateful to Marshall Cohen for sending us details of the optical spectrum of this object. We thank a referee for a careful examination of the data we have discussed, and for emphasizing the need for more optical detail.

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