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X-RAY–EMITTING QSOs EJECTED FROM ARP 220

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ABSTRACT

Four compact *ROSAT* X-ray sources very close to the nearby ultraluminous infrared galaxy Arp 220 (IC 4553) have been identified as medium-redshift QSOs. The closest pair lying symmetrically across the galaxy have almost identical redshifts $z = 1.25$, 1.26. All of the evidence suggests that these QSOs have been ejected from Arp 220 and have large intrinsic redshifts.

Subject headings: galaxies: distances and redshifts — galaxies: individual (Arp 220) — quasars: general — X-rays: galaxies

1. INTRODUCTION

Arp 220 (IC 4553) is a nearby ultraluminous infrared galaxy ($z = 0.018$) that is a strong X-ray source. Close to its center there are a number of fainter objects with several different, larger redshifts. Ohyama et al. (1999) have published optical images and have given spectroscopic data on the components of this rich field, which they have shown in their Figures 1–4. One of us (H. C. A.) has mapped the X-ray field around the galaxy from the photon event files in the archives of the *ROSAT* satellite, as shown in Figures 17, 18, and 19 in Arp (2001a).

Of particular interest are four compact *ROSAT* X-ray sources, which coincide with stellar images seen on the Palomar Observatory Sky Survey. The brightest within 50′ radius have been named 20.3N and 20.3S (the numbers corresponding to the *ROSAT* counts per kilosecond). The brightest in the inner field are Arp 2 and Arp 9. Their remarkable alignment across Arp 220 is shown in Figure 1. The basic data 2000 coordinates and magnitudes of the optical objects are given in Table 1, together with the coordinates and magnitudes of three faint stellar objects discovered and discussed by Ohyama et al. (1999). In § 2 we give the spectroscopic data for Arp 2 and 9, and 20.3N and 20.3S, showing that they are all QSOs. In § 3 we relate these results to similar detections associated with other active galaxies.

2. POSITIONS, MAGNITUDES, AND SPECTROSCOPY

Figure 1 shows the *ROSAT* X-ray data, which led to the identification of the optical objects Arp 2 and 9. They are seen to be equally strong X-ray sources, directly aligned and essentially equidistant at 8′.0 and 7′.0 from the cataloged center of Arp 220. In Figure 2 we show a plot of the locations of these X-ray sources and also the outer bright pair of *ROSAT* sources with exactly equal numbers of counts per kilosecond, 20.3N and 20.3S.

In Table 2 we give our spectroscopic data for these four QSOs. For Arp 2, 9, and 20.3S, observations were made with the Kast spectrograph on the 3 m Shane Telescope at Lick Observatory, and, for 20.3N, the data were obtained with the OMR spectrograph on the 2.16 m telescope at Xinlong Station, Beijing Astronomical Observatory. Figure 3 shows the remarkably similar spectra of Arp 2 and 9. This similarity is indeed striking. Our surprise, when we observed Arp 9 after Arp 2 and saw from the quick-look data the same three broad emissions coming up at the same wavelengths, can well be imagined.

It is clear from these results that we have found two pairs of QSOs, one pair of objects at almost exactly the same angular distance from Arp 220 with redshifts that differ only by less than $z = 0.009$ and a second pair at distances of 29′.8 and 43′.1, respectively. As far as the first pair is concerned, the similarity of the redshifts and the fact that they lie along an axis through the nucleus of Arp 220 and are at roughly the same distance in opposite directions makes it highly unlikely that this is an accidental configuration. The second pair is not as symmetrically placed, and the redshifts are not equal. Thus, formally the probability that this configuration is accidental is higher than it is for the first pair. However, both QSOs, 20.3N and 20.3S, are bright (16.3 and 17.7 mag), and the surface density of QSOs as bright as this is very low, $\lesssim 0.1$ deg^{-2} for magnitudes 16 and 17 (Kilkenny et al. 1997). Thus, even ignoring the geometrical configurations, to find two such bright unrelated QSOs in an area of ~ 2 deg^2 is highly unlikely.

The most likely explanation is that all four of these QSOs are physically associated with Arp 220 and have been ejected from it, so the redshifts are largely intrinsic in origin.

Heckman et al. (1996) suggested that part of the diffuse X-ray emission from Arp 220 is due to the faint compact group of galaxies about 2′ southwest of the center; their *ROSAT* contours cover Arp 220 and these galaxies. We confirm this as shown here in Figure 1. Ohyama et al. (1999) have obtained spectra of these objects and have shown that they are galaxies showing stellar absorption features at a redshift $z = 0.09$. In carrying out their investigation they found three faint objects ($m = 24.5$), which they call galaxies but in which the only features that are detected are emission lines due to Mg II, [O II], [O III], [Ne III], and, in one case, Hβ. They have redshifts $z = 0.528$, 0.529, and 0.523. The spectra suggest that the objects can be classified as active galactic nuclei (AGNs) or starburst nuclei and not normal background galaxies. Thus, they are probably related to the other QSOs around Arp 220. These redshifts are close to that of the QSO 20.3S, and they lie about 2′.5 from the center of Arp 220. They are included in Table 1.

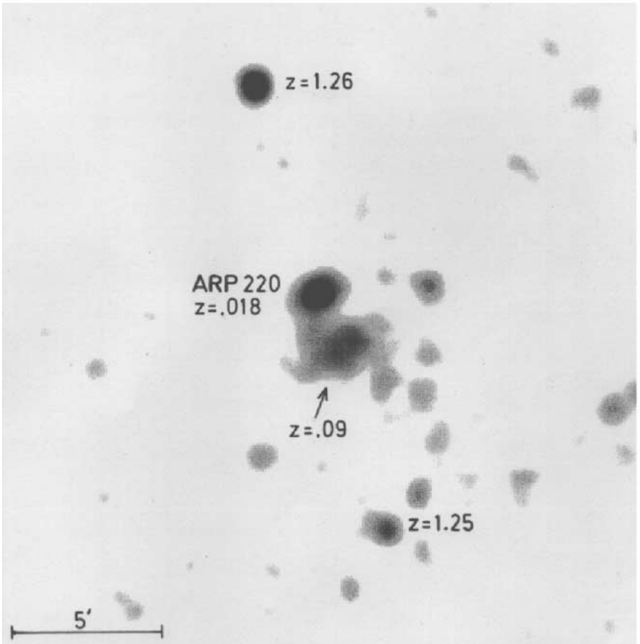

FIG. 1.—Hard X-ray band (0.5–2.4 keV), from *ROSAT* PSPC, showing a pair of strong sources across Arp 220. Note the curved string of sources leading down to the southeast QSO. Known redshifts are labeled.

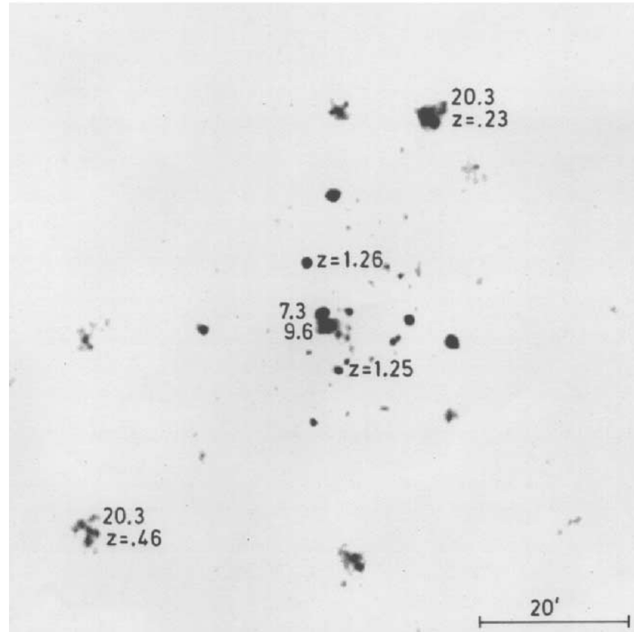

FIG. 2.—Larger field of view in X-rays around Arp 220. In addition to redshifts, some X-ray intensities are labeled in counts per kilosecond. Note the strong and equal count rates for the two outer quasars.

3. DISCUSSION

By now it has been long accepted that radio jets and lobes, often accompanied by X-ray jets and X-ray–emitting material, are ejected, in generally opposite directions, from active galaxies. Since compact, energetic X-ray sources must be relatively short-lived, it is natural to suppose that the excess density of X-ray sources around active galaxies (Radecke 1997) have been mostly recently ejected. Their concentration around Arp 220 further supports this conclusion (Arp 2001a).

The outer pair of quasars here conform to the usual pattern of ejected quasars, with the redshifts of $z = 0.232$ and 0.458 lying on each side of one of the redshift peaks (at $z = 0.3$) found in the redshift distribution of several samples of QSOs (Burbidge & Napier 2001).

Why then do the two inner quasars have such similar redshifts? An obvious possibility is that they have been ejected across the line of sight. There are, however, other close redshift pairings that strain somewhat the statistical probability of orientation. A more reasonable expectation is that, when ejection does not occur along the minor-axis direction, the quasar or protoquasar interacts strongly with the material of the ejecting galaxy and its ejection velocity is slowed drastically. This would furnish an explanation for the extreme disruption of, in this case, Arp 220. (See also Arp 1999 for a similar case.) Another advantage of this explanation is that the unusually red color of QSO 2 ($O-E = 2.18$ mag) could be explained as due to entrained dust associated with the very dusty Arp 220.

Finally, the group of strong X-ray galaxies about 2′ southwest of Arp 220 are indicated to be attached by H I 21 cm isophotes (measures by J. Hibbard; see Arp 2001a). From Figure 1 we see that this connection is present in the X-ray contours. Thus, despite the fact that the redshifts are greater than that of Arp 220, they may represent ejected material from Arp 220. Patches of X-ray material are seen in Figure 1 to lead from Arp 220 in a somewhat curved track down through this group almost exactly to the southwest QSO 9.

TABLE 1
QSOs AND AGNs CLOSE TO ARP 220

Object	α (2000)	δ (2000)	m	Distance from Center (arcmin)
20.3N	15 33 54.7	+23 56 15	16.34	29.8
Arp 9	15 34 48.1	+23 22 31	19.82	7.0
Ohyama I[a]	15 34 54.3	+23 27 59	24.5	2.33
Ohyama II[a]	15 34 54.5	+23 27 52	24.3	2.43
Ohyama III[a]	15 34 54.8	+23 27 44	24.7	2.54
Arp 2	15 35 06.1	+23 36 56	19.61	8.0
20.3S	15 37 14.5	+23 00 40	17.74	43.1

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.
[a] Data from Ohyama et al. 1999.

TABLE 2
REDSHIFTS OF FOUR X-RAY QSOs AROUND ARP 220

QSO	Line	λ (Observed) (Å)	z	Mean z
Arp 9	Mg II 2799	6295	1.249	
	C III] 1909	4290	1.247	
	C IV 1549	3485	1.250	
				1.249
Arp 2	Mg II 2799	6326	1.258	
	C III] 1909	4311	1.258	
	C IV 1549	3496	1.257	
				1.258
20.3N	Hα	8084	0.2318	
	[O III] 5007	6172	0.2327	
	Hβ	5993	0.2329	
				0.2325
20.3S	Hα	9610	0.4644	
	[O III] 5007	7320	0.4621	
	[O III] 4959	7252	0.4624	
	Hβ	7108	0.4622	
	Hγ	6350	0.4631	
	Mg II 2799	4093	0.4623	
				0.4627

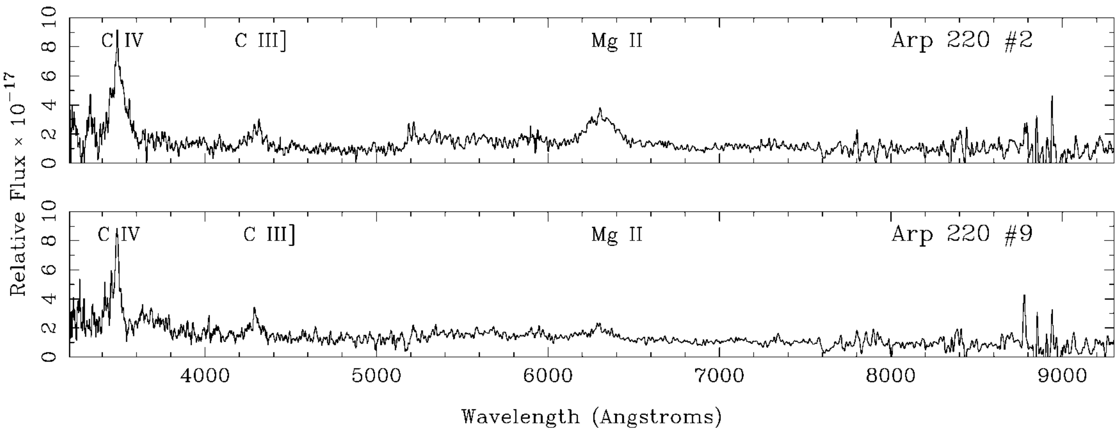

FIG. 3.—Spectra of the two quasars pictured in Fig. 1, $z = 1.26$ (*top*) and $z = 1.25$ (*bottom*). Spectra are from the 3 m Shane telescope of Lick Observatory.

4. CONCLUSIONS

We have presented new observational evidence showing that two pairs of X-ray QSOs are associated with the comparatively nearby active galaxy Arp 220 and most likely have been ejected from it.

This is not the first evidence of this kind. Earlier we showed that a similar pair of X-ray–emitting QSOs lie at approximately the same angular distance from NGC 4258 and were most likely ejected from it (Burbidge 1995). A similar but wider pair was also identified across NGC 2639, differing in z by only 0.018 (Burbidge 1997). Lines of ejected quasars have been reported across the Seyfert galaxies NGC 3516 and NGC 5985 (Chu et al. 1998; Arp 1998), and a concentration of quasars around NGC 1068 (Burbidge 1999). Recently, three quasars of $z =$ 0.358, 0.376, and 0.380 have been reported around the X-ray jet galaxy NGC 6217. The latter two quasars with a difference of only 0.004 in z are aligned rather well across the galaxy. (See Arp 2001b.) Two of these quasars are extremely red, suggesting interaction with material in the galaxy as was inferred for Arp 220.

It is interesting to note that NGC 6217, mentioned above, is also cataloged as Arp 185. This means that the morphological classifications of peculiar galaxies (Arp 1966) between about Arp 140 and Arp 230 are turning up many highly significant associations with quasars and high-redshift companions. The ones that have been investigated so far are 152, 157, 185, 189, 212, 220, and 227.

It appears to us that the inescapable conclusion is that many QSOs are not at the distances suggested by their redshifts but have large intrinsic components and are associated with parent AGN galaxies.

It is a particular pleasure to thank Geoffrey Burbidge for his help throughout the work described here. Sincere thanks are also due to Vesa Junkkarinen (UCSD) for acquisition of near 20 mag stellar objects against the bright sky over San Jose, to Lick Observatory telescope operators John Morey and Kostas Chloros, and to John O'Meara (UCSD) for the data reduction and preparation of Figure 3.

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