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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: Key Words: Galaxies: distances and redshifts - - - Galaxies: individual(Arp 220) - - - Quasars: general - - - X-rays: galaxies

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, (HCA), 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 arc min 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 No. 2 and Arp No. 9. Their remarkably exact alignment across Arp 220 is shown in Figure 1. The above four X-ray sources

appear to be two roughly symmetrically placed pairs which we show in Figure 2. 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 Section 2 we give the spectroscopic data for Arp Nos. 2 and 9, and 20.3N and 20.3S, showing that they are all QSOs. In Section 3 we relate these results to similar detections associated with other active galaxies.

Positions, Magnitudes and Spectroscopy

Figure 1 shows the ROSAT X-ray data which led to the identification of the optical objects Arp Nos. 2 and 9, labeled RSO (red stellar object) and BSO (blue stellar object). They are seen to be essentially equidistant at 7.0 and 8.0 arc min from the catalogued 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/ksec, 20.3N and 20.3S.

In Table 2 we give our spectroscopic data for these four QSOs. For Arp Nos. 2 and 9 (RSO and BSO), 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 Nos. 2 and 9. This similarity is indeed striking. Our surprise when we observed No. 9, after No. 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 arc min respectively (Figure 2). 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 of the QSOs, 20.3N and 20.3S are bright (16.3m and 17.7m), and the surface density of QSOs as bright as this is very low (0.1/square degree for magnitudes 16 and 17 (Kilkenny et al. 1997; Boyle et al. 1990; Goldschmidt

et al. 1992). Thus, even ignoring the geometrical configurations, to find such bright unrelated QSOs in an area of ~ 2 square degrees 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 that the redshifts are largely intrinsic in origin.

Heckman et al. (1996) have suggested that part of the diffuse X-ray emission from Arp 220 is due to a faint compact group of galaxies about 2' southwest of the center. We confirm this as shown here in our Fig 1. Ohyama et al. (1999) have obtained spectra of these three 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], [NeIII] 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 AGN or starburst nuclei and not normal background galaxies. They are thus indicated to be related to the other QSOs around Arp 220. These redshifts are close to that of the QSO 20.3S and lie about 2'.5 from the center of Arp 220. They are included in Table 1.

Evidence for Ejection

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 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 confirm the usual pattern of ejected quasars. If their redshifts of z = .232 and .458 are corrected to the reference frame of Arp 220 (z = .018) the redshifts come out z = .432 and .210. That gives a mean redshift of z = .32 which is almost exactly the quantized value of z = .30! This enables one quasar to have been ejected toward us with a line-of-sight velocity component of v = +.10c and one away from us with v = -.07c. This is close to what has been found for the 10 previous best pairs discussed by Narlikar and Arp (2001).

Why then are the two inner quasars so close in redshift at z = 1.25 and 1.26? An obvious possibility is that they have been ejected across the line of

sight. It will be mentioned in the next section, however, that there are other close redshift pairings which strain somewhat the statistical probability of orientation. A more reasonable expectation is that when ejection does not occur along the usual path of least resistance, the minor axis direction, that the quasar or proto quasar interacts strongly with the material of the ejecting galaxy and is slowed drastically in its ejection velocity. This would furnish a very natural 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 No. 2 (O-E = 2.18 mag.) could be naturally explained as entrained dust from the enormous amounts of dust associated with Arp 220.

Nos. 2 and 9 have redshifts almost exactly between the z = .96 and z = 1.41 peak. That is quite unusual - perhaps they are caught in a short moment of transit between two major peaks.

Finally the group of strong X-ray galaxies about 2 arcmin SW of Arp 220 are indicated to be attached by HI radio isophotes (measures by J. Hibbard, see Arp 2001a). They are clearly continuous with Arp 220 in X-rays as shown here in Fig. 1. At their conventional redshift distance with z = .09 they would be excessively luminous - close to supposed conventional quasar

luminosities! It is suggested here that they represent ejected material which has been stopped close to Arp 220. Patches of X-ray material are seen in Fig. 1 to lead from Arp 220 in a somewhat curved track down through this group almost exactly to the SE QSO, No. 9.

Discussion and 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 have shown 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). Recently three quasars of z = .358, .376 and .380 have been reported around the X-ray jet galaxy NGC 6217. The latter two quasars with only a difference of .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 catalogued 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. Just the ones which have happened to be investigated so far are: 152, 157, 189, 212, 220 and 227.

If the distance of NGC 4258 is 7 Mpc and Arp 220 with a redshift z = 0.018 is at a distance of 90 Mpc (Ho = 60 km/sec Mpc-1) then we would have to accept QSOs with a wide range of absolute magnitudes. It has been argued, however that Arp 220 is much closer than its redshift distance (Arp 2001a) and it may then be possible to deal with a much more homogeneous population of low luminosity, high intrinsic redshift objects.

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TABLE 1

QSOs and AGN Close to Arp 220

Object	α(2000)			δ(2000)			m	Distance from Center
	h	m	s	^{o}	$'$	$''$		(arc min)
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	15	34	54.3	+23	27	59	24.5	2.33
*Ohyama II	15	34	54.5	+23	27	52	24.3	2.43
*Ohyama III	15	34	54.8	+23	27	44	24.7	2.54
Arp 2	15	35	6.1	+23	36	56	19.61	8.0
20.3S	15	37	14.5	+23	00	40	17.74	43.1

***Data from Ohyama et al. (1999).**

TABLE 2

Redshifts of Four X-Ray QSOs Around Arp 220

QSO, 2000 Coordinates	Line	λ(obs)	z
Arp No. 9 (BSO)	Mg II 2799	6295	1.249
	C III] 1909	4290	1.247
	CIV 1549	3485	1.250
		Mean	1.249
Arp No. 2 (RSO)	Mg II 2799	6326	1.258
	CIII] 1909	4311	1.258
	CIV 1549	3496	1.257
		Mean	1.258
20.3 N	Hα	8084	0.2318
	[O III] 5007	6172	0.2327
	Hβ	5993	0.2329
		Mean	0.2325
20.3 S	Hα	9610	0.4644
	[O III] 5007	7320	0.4621
	[O III] 4959	7252	0.4624
	Hβ	7108	0.4622
	Hγ	6350	0.4631
	MgII 2799	4093	0.4623
		Mean	0.4627

Figure Captions

Fig. 1 - Hard X-ray band (.5 to 2.4 keV), from ROSAT PSPC, showing pair of strong sources across Arp 220. Note curved string of sources leading down to SE 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/ks. Note strong and equal count rates for the two outer quasars.

Fig. 3 - Spectra of the two quasars pictured in Fig. 1, z = 1.26 on top and z =1.25 below. Spectra from 3m Shane telescope of Lick Observatory.

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