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ASTRONOMY AND ASTROPHYSICS

A QSO 2.4 arcsec from a dwarf galaxy - the rest of the story

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Abstract. D. Reimers and H.-J. Hagen report in A&A 329, L25 (1998) that a QSO of $z = .807$ is a "by chance projection" on the center of a galaxy of $z = .009$. A considerable amount of previously published evidence would lead us to expect an active, low redshift galaxy within about one degree of such a quasar. It is shown here that, in fact, there is a bright Seyfert galaxy of $z = .008$ only 36.9 arcmin distance. Moreover, it turns out that a total of five quasars, plus the dwarf galaxy, are accurately aligned along the minor axis of this Seyfert with the quasars in descending order of redshift, i.e., $z =$2.13, 1.97, .81, .69 and .35.

Key words: Galaxies: active – Galaxies: individual: NGC5985 – *(Galaxies:)* quasars: general – Galaxies: Seyfert

1. Introduction

A very blue galaxy, SBS 1543+593, was discovered in the second Byurakan survey (Markarian et al. 1986). The Hamburg objective prism survey (Hagen et al. 1995) rediscovered it as a quasar and subsequent spectra and imaging revealed it to be a quasar of $z = .807$ only 2.4 arcsec from the center of a galaxy of dwarf characteristics (Reimers and Hagen 1998).

Despite computing the probability of chance proximity as 1.5×10^{-3}, Reimers and Hagen stated that the center of the galaxy was a chance projection on a background quasar. It was not taken into account, however, that large, and statistically significant, numbers of quasars fell very close to many other low redshift galaxies (for lists of cases see G.R.Burbidge 1996). Moreover, Reimers and Hagen themselves estimated that the QSO was very little reddened. Of course if it was behind the inner part of the dwarf spiral it should have been noticeably reddened. [1]

The dwarf spiral, however, did not seem like a galaxy with an active nucleus which would eject a quasar. *Therefore I asked the question: "Is there a nearby galaxy which could be the origin of the quasar?"* It quickly turned out that only 36.9 arcmin distant was the very bright (V = 11.0 mag.) Seyfert galaxy, NGC5985. This was just the distance within which quasars were found associated at a 7.4 sigma significance with a large sample of Seyferts of similar apparent magnitude (Radecke 1997; Arp 1997a). The following sections present the full census of objects around the Seyfert NGC5985.

2. The quasars around the Seyfert NGC5985

Fig. 1 shows a plot of all the catalogued active galaxies (Véron and Véron 1996) in an area 3.4 x 2.4 degrees centered on NGC-5985. It is apparent that there is only one active galaxy in the area and it is the bright, Shapley-Ames Seyfert, NGC5985. The chance of finding a Seyfert galaxy this bright, this close to the $z = .81$ quasar is $< 10^{-3}$.

One caveat is that if the $z = .009$ galaxy is lensing the $z = .81$ QSO then this probability will increase because of the tendency of galaxies to cluster. We have, however, argued against the lensing hypothesis on the basis that the QSO appears unreddened. Reimers and Hagen also have suggested that the central mass of the galaxy may be too small for lensing to be important.

All catalogued quasars, plus the new QSO of $z = .807$ and its companion are also plotted. It turned out all quasars are from a uniformly searched region in the second Byurakan survey. Since five of the six quasars are aligned within about $\pm 15°$ accuracy one can compute the probability of their accidental alignment as $P_6^5(\leq 15°) = 6 \times 10^{-4}$. But then one must factor in the probability that the line would agree with an *a priori* minor axis direction. This would reduce the probability by another factor of 10^{-2}. The total probability of accidentally finding this prototypical configuration is then of the order of 10^{-8} to 10^{-9}.

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[1] For S_d spirals Sandage and Tamman (1981) use mean absorptions of .28 to .87 mag. ranging from face-on to edge-on systems. For a quasar entirely behind the galaxy this would give $.6 \lesssim A_B \lesssim 1.7$ mag. and $.15 \lesssim E_{B-V} \lesssim .44$mag. However the quasar here would have to shine through a region very close to the center where the absorption is much higher than average. For example, Hummel, van der Hulst and Keel (1987) show absorptions to the center of the late type spiral NGC 1097 to be $.3 \lesssim A_v \lesssim 3.0$mag. That would translate to a full reddening of $.2 \lesssim E_{B-V} \lesssim 2.0$mag. which again would be conspicuous.

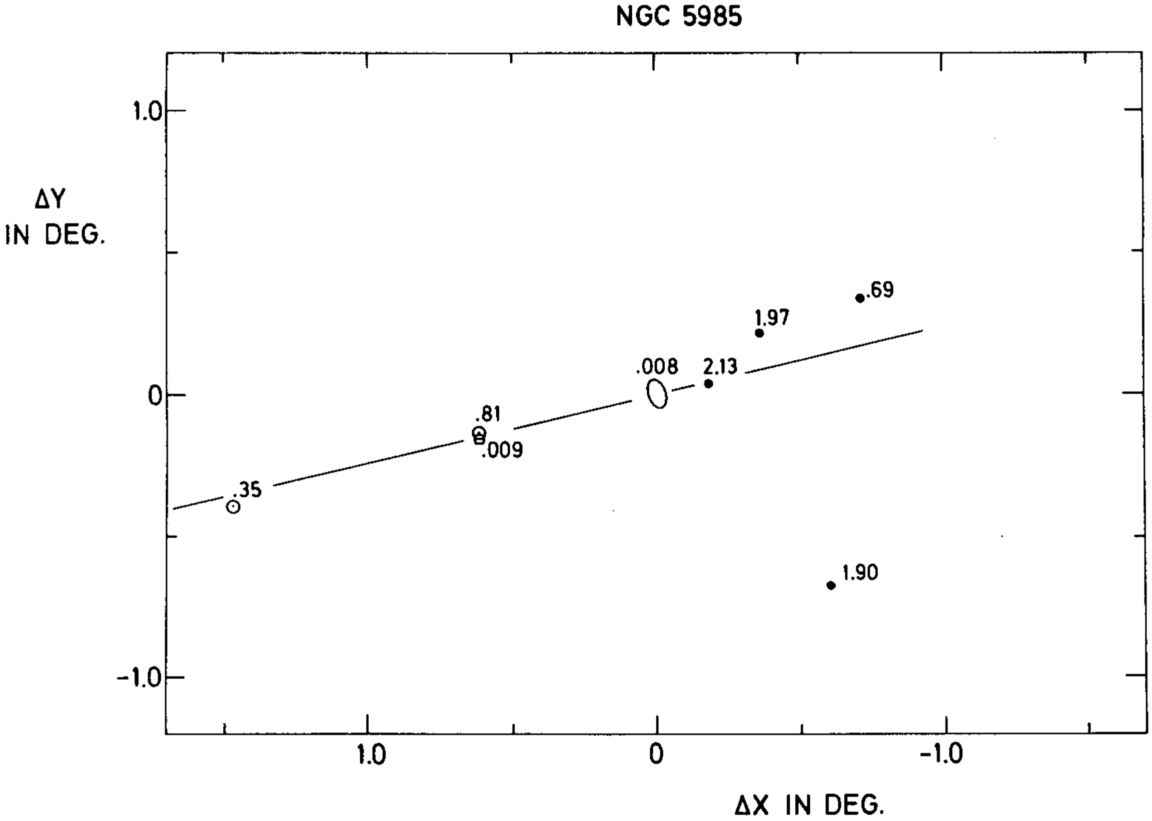

Fig. 1. All catalogued active galaxies and quasars within the pictured area are plotted. Redshifts are labeled. The dwarf spiral 2.4 arc sec from the z = .81 quasar has a z = .009 which marks it as a companion of the Seyfert NGC5985 at z = .008. The line represents the position of the minor axis of NGC5985.

Table 1. Objects in the field around NGC5985

Object	Type	Vmag.	z	R.A.(2000)	Dec.	Δx°	Δy°	r'
NGC5985	Sey1	10.98	.008	15/39/37.5	+59/19/58	—	—	—
HS 1543+5921	QSO	16.4	.807	15/44/20.1	59/12/26	.6019	-.1256	36.9
SBS 1543+593	dSp	16.9	.009	//	24	//	-.1262	//
RXJ 15509+5856	S1	16.4	.348	15/50/56.8	58/56/04	1.4535	-.3984	90.4
SBS1537+595	QSO	19.0	2.125	15/38/06.0	59/22/36	-.1944	+.0439	12.0
SBS1535+596	QSO	19.0	1.968	15/36/45.7	59/32/33	-.3644	+.2097	25.2
SBS1533+588	QSO	19	1.895	15/34/57.2	58/39/24	-.6016	-.6761	54.3
SBS1532+598	QSO	18.5	.690	15/33/52.8	59/40/19	-.729	+.339	48.2

Whether one considers the $z = 1.90$ quasar an unrelated interloper or an ejection in a different direction does not change the calculation appreciably.

The parameters of the objects in this field are listed in Table 1. Their distances from NGC5985, at the center of the field, are calculated in degrees.

3. Similar associations which have been previously published

From 1966 onward, evidence that quasars were associated with low redshift galaxies has been presented (for review see Arp 1987). Since the discovery of a pair of quasars across the Seyfert NGC4258 (Pietsch et al. 1994; E.M.Burbidge 1995), however, bright Seyfert galaxies have been systematically analyzed (Radecke 1997; Arp 1997a). The latter investigations demonstrated physical associations at greater than 7.5 sigma for quasars within about $10' < r < 40'$ of these active galaxies.

The alignment of quasars shown in Fig. 1 exhibits the same properties found in the previously published results except that the scale of the separations and apparent magnitudes of the quasars in the NGC5985 system suggest it may be somewhat closer than the average Seyfert previously investigated. In the NGC-5985 association, however, there are more than the usual pair of

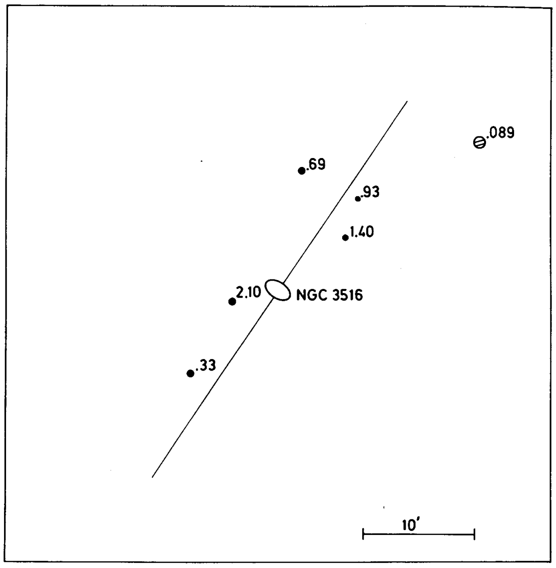

Fig. 2. All the X-ray bright quasars around the bright Seyfert NGC3516 are plotted with their redshifts labeled. (From Chu et al. 1998). The line represents the direction of the galaxy minor axis.

quasars so that the line is very well defined. In this respect it is another crucial case like the 6 quasars associated with NGC3516 (Chu et al. 1998). The NGC3516 case is shown here in Fig. 2 for comparison.

4. Alignment along the minor axis

Early in the association of quasars with active galaxies it was noticed that there was a tendency for them to lie in the direction of the minor axis of the galaxy. When the X-ray pairs began to be identified this correlation strengthened (Arp 1997c; 1998a,b). Particularly in Arp (1998a,b) it was shown that the quasars associated with Seyferts with well defined minor axes fell along this minor axis within a cone of about $\pm 20°$ opening angle. These same references showed companion galaxies, as in the present case of NGC 5985, also preferentially falling along this same axis. With the observations of NGC3516 shown in Fig. 2, however, there appeared a continuous definition of the minor axis by the quasars.

The most striking aspect of the NGC5895 case now becomes the fact that the line in Fig. 1 was not drawn through the quasars as one might assume! The line in Fig. 1 actually plots the direction of the minor axis of the Seyfert as recorded in the Uppsala General Catalogue of Galaxies (Nilson 1973).

There are two important conclusions to be drawn: The first is that the quasars must originate in an ejection process. The minor axis is the expected ejection direction from an active galaxy nucleus (see also the discussion of ejection along the minor axis in NGC4258 in Burbidge and Burbidge 1997). The second is that the chance of the observed quasars falling so closely along a *predicted* line by accident is negligible, thus confirming at an extraordinarily high level of significance the physical association of the quasars with the low redshift galaxy.

5. The role of companion galaxies

What is the origin of the dwarfish spiral only 2.4 arcsec from the $z = .81$ quasar? The simplest answer is that it represents entrained material from NGC5985 which accompanied the ejection of the $z = .81$ quasar. The redshift of NGC5985 is $z = .008$ and the redshift of the dwarf spiral is $z = .009$. The latter redshift and its distance from NGC5985 would pretty clearly identify it as a physical companion of the Seyfert.

It has been suggested that dwarfs are associated with ejection from a central galaxy and an example is the string of dwarfs coming from the X-ray ejecting NGC4651 (Arp 1996, Fig.6). But, in general, companion galaxies have been identified since 1969 as falling preferentially along the minor axes of their central galaxy. This has been interpreted as high redshift quasars evolving to lower redshifts and finally into companion galaxies (Arp 1997b; 1998a,b). The line of ejection seems to be remarkably stable from NGC5985 so objects of older evolutionary age could be going out or falling in along the same track. This would give a much higher chance of the quasar and the dwarf being accidently nearby at any time. In fact, observing quasars and galaxies lying along the same ejection lines from active galaxies gives for the first time an explanation for the many cases of close associations of higher redshift quasars with low redshift galaxies (G. Burbidge 1996) and higher redshift quasars with lower redshift quasars (Burbidge, Hoyle and Schneider 1997). *I also note the presence of three NGC companion galaxies closely along NGC5985's minor axis to the NW. These are of fainter apparent magnitude and one of them has a measured redshift (z = .0095), similar to the dwarf SE in that it has a few hundreds of km/sec higher redshift than the parent Seyfert. This is just as had been found for the redshift behavior of companion galaxies (see Arp 1998a,b).*

6. Intrinsic redshift vs angular separation from the galaxy

Since the quasars are strictly ordered in decreasing redshift with distance from the central galaxy in NGC5985, it is interesting to compare the relation with the one in NGC3516 where they are also so ordered. Fig. 3 show several interesting results:

- The slopes of the relation in both systems are closely the same. Since the plot is in ln r, this means the relationship is exponential with the same exponent in both cases.
- The constant separation between the two slopes translates into a difference in scale between the two systems of a factor of about 4.5.

The latter scale factor could be accounted for if the NGC5985 system were closer to the observer than the NGC3516 system. What do the apparent magnitudes suggest? The central Seyfert NGC5985, in dereddened magnitudes, is about 1.33 mag. brighter than NGC3516. The apparent magnitudes of the quasars in

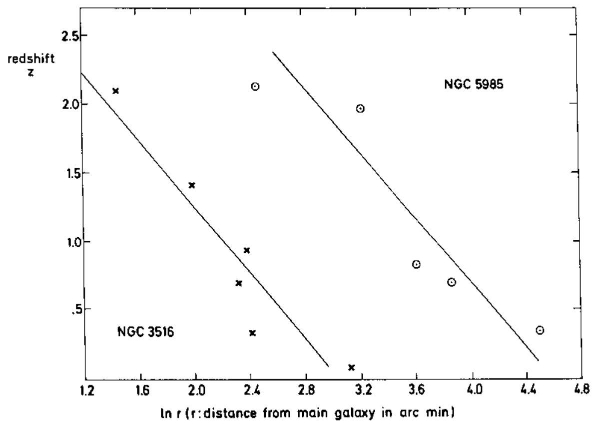

Fig. 3. The relation between the redshift of the quasars and their distance from the active galaxy for the two best cases of multiple, aligned quasars. The exponential law is indicated to be similar but the scale of the NGC5985 relation is larger by a factor of about 4.5, indicating NGC5985 is nearer the observer and/or oriented more across the line of sight.

the NGC3516 association have not been accurately measured but the quasars in the NGC5985 system appear to be 2 to 2.5 mags. brighter than quasars measured around Seyferts generally at the distance of the Local Supercluster. If we therefore estimate that NGC5985 is at a distance modulus about 2 mag. closer than NGC3516 then the scale of the alignment should be about 2.5 times greater. Since the projected ellipticities of the two galaxies suggests the minor axis of NGC3516 is oriented at least 45% closer to the line of sight, a total scale difference of 3.6 out of 4.5 is accounted for.[2] It seems quite possible that the separation of the quasars from the galaxies as a function of intrinsic redshift is quite similar. This is an important result to refine because it implies, for similar ejection velocities, that the evolution rate to lower redshifts with time is a physical constant.

One further comment concerns the quasars near $z = 2$. As found in previous associations they are more than 2 magnitudes fainter than the $z \approx 0.3$ to 1.4 quasars. This predicts that for the majority of Seyferts which have medium redshift quasars in the 18 to 19th mag. range, that their $z = 2$ quasars should be found in the 20 to 21+ mag. range and closer to their active galaxy of origin. These quasars, generally weak in X-rays, should be searched for with grism detectors on large aperture telescopes such as was done for M82 (E.M. Burbidge et al. 1980).

7. Quantization of redshifts

NGC3516 was unusual in that each of the six quasars fell very close to each of the major redshift peaks observed for quasars in general. For radio selected quasars with $S_{11} > 1$Jy it was shown (Arp et al. 1990) that the Karlsson formula

$$(1 + z_2) = (1 + z_1)1.23$$

$$z_n = .061, .30, .60, .96, 1.41, 1.96, 2.64 \ldots$$

was fitted with a confidence level of 99 to 99.97%. In the present NGC5985 case, four of the five quasars fall close to the quantized redshift values. Therefore, together with NGC 3516, in the two best cases of multiple, aligned quasars the redshifts fall very close to the formula peaks in 10 out of 11 cases. The z = .81 redshift then may represent a short-lived phase in evolution from the .96 to the .60 peak.

8. Summary

Examination of catalogued objects in the vicinity of a QSO only 2.4 arcsec from a dwarf galaxy reveal that this pair of objects, as well as four additional quasars, are associated with a nearby, bright Seyfert galaxy.The configuration satisfies all the criteria of previous quasar - active galaxy associations. In particular the NGC5985 alignment of five quasars defines well the minor axis of the galaxy as does the alignment of six quasars through the Seyfert NGC3516. The similar decline in quantized redshift values with increasing distance from the active galaxy suggests there is one law of redshift evolution with time.

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[2] The inclination of NGC 5985 is taken from de Vaucouleurs et al. (1976) and of NGC3516 from Arribas et al. (1997).