X-ray Observations of NGC 1097 and Nearby Quasars

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Abstract

Observations of three different sized regions centered on the optical jet spiral, NGC 1097 have been made with ROSAT. The PSPC observations show a striking excess of bright and medium flux X-ray sources around this hot spot nucleus, Seyfert 1 galaxy. The brightest of these sources are catalogued quasars which suggests the fainter X-ray sources are predominantly quasars also. If so, of the order of at least 10 and possibly considerably more X-ray quasars appear to be associated with NGC 1097 within a radius of $20'$.

There is a marked segregation, with bright X-ray sources on the side of the bright optical jets and weak X-ray sources on the side of the fainter optical jets. Some, but not all, of this asymmetry could be accounted for by absorption in the plane of the spiral being tilted towards us on the weak source side. Both optical and X-ray evidence point to strong absorption in the disk of NGC 1097 which reaches far beyond the optical limits.

High resolution imaging (HRI) of regions closer to NGC 1097 reveal some fainter pairs and lines of X-ray sources aligned across the nucleus near the cones defined by the optical jets. Filaments and patches of ultraviolet emission (1500–1700Å) appear to fill in the region between the strong optical jets in the direction of the bright X-ray quasars, suggesting physical association of the ultraviolet emission with the quasars and the galaxy.

Finally, ROSAT SURVEY observations have been examined over a 4 × 4 degree field centered on NGC 1097. A line of X-ray sources going through the galaxy in the direction of the strongest optical jet includes a strong X-ray quasar *with its X-ray isophotes extended toward NGC 1097.* In approximately the opposite direction, 1.9 degrees distant, is a strong X-ray source ($.5ctss^{-1}$) which is here identified with a 16.5 mag. BL Lac object.

Key words: galaxies – Seyfert-galaxies – quasars:general

1 Introduction

The most extensive optical jet system of any known galaxy was discovered in NGC 1097 by Wolstencroft and Zealey (1975). The jets were of low surface brightness but clearly originated in or near the nucleus of this $B_T^0 = 9.75 mag.$, $cz_0 = 1284 kms^{-1}$, hot spot nucleus, spiral (Arp, 1976; Lorre 1978). Red and blue CTIO 4 meter photographs have been combined in Fig.1 to give a deep, color picture of the galaxy. When X-ray observations by the Einstein Laboratory revealed strong X-ray sources in the region of the strongest optical jets, optical identifications were made and resulted in spectroscopic confirmation of six quasars. (Wolstencroft, et. al 1983). Later a 2.85 × 2.85 degree field around NGC 1097 was searched with objective prism schmidt plates and 31 quasars were confirmed with slit spectra (Arp, Wolstencroft and He 1984). The density of quasars was in excess of background, extended to about one degree radius from the galaxy and reached a factor of > 20 excess in a region centered between the two strongest jets.

The present paper reports new X-ray observations with ROSAT which cover regions of diameter $\sim 20'$ (HRI), $\sim 40'$ (PSPC) and 4×4 deg. (Survey). Results are here presented on both point and extended X-ray sources in the regions centered on NGC 1097.

2. PSPC observations

On 27 Dec 92 an observation of 9638 seconds was made with ROSAT PSPC. Table 1 lists 49 sources detected with the Standard Analysis (SASS) program. Such a large number of X-ray sources detected in a 9.6 ks^{-1} exposure is striking. For example, in the Mark474 field a 12.9ks^{-1} exposure detected only 25 sources. A 10.5 ks exposure detected only 24 sources in the NGC 4651 field and both of these fields had associated X-ray sources (Arp 1994). In the next section we will calculate the specific overdensity of these X-ray sources around NGC 1097.

The brighter X-ray sources are shown in color in Fig.2. It is clear that a conspicuous group exists about $11'$ north of NGC 1097. Four of these X-ray sources are identified with previously measured optical quasars as noted in Table 1. The previous designation of these quasars was #23, 26, 27 and 28 (Arp, Wolstencroft and He 1984). The corresponding SASS numbers in Table 1 are nos. 12, 8, 18 and 10.

In Fig. 3 we show the PSPC X-ray sources inside a box 4000×4000 pixels $= 33.3 \times 33.3$ arc min. The 0.7-2.35 keV band is selected in order to show best the many hard sources around NGC 1097. To the level shown, 0.18 counts per 5 arc sec quare image pixel, all of the sources are detected by SASS. Identifying numbers from Table 1 are appended to a deeper version of Fig.3 which is shown in Fig.5. Fig.3 is shown here in order to emphasize the striking segregation of strong sources on the north and weak sources on the south side of NGC 1097. In the following sections we will explore how many of these sources can be expected to belong to NGC 1097 and what might account for their assymetrical distribution.

2.1 Computing the excess of X-ray sources

One problem has to be dealt with before the density of X-ray sources around NGC 1097 can be derived. The problem is that one of the brightest X-ray sources, QSO# 26, at just the time of the PSPC obserations, was in an extraordinarily low state. Table 2 shows that it was a factor of 15 to 30 lower than average.

In order to ascertain what its average state was, all the previous X-ray measures in the NGC 1097 field were assembled in Table 2. The average of the three most reliable previous measures was $Fx = 3.7 \times 10^{-13} erg cm^{-2} s^{-1}$ and this is the value used in the computation of log N/log S values for quasar #26 and shown as a circle in Fig.4.

Table 2
History of X-ray Observations of Bright Objects in NGC 1097 Field
Fluxes (Fx) $\times 10^{-13} cgs$ in approximately the $.5 < keV < 2.0$ band

SASS No.	Object	redshift	PSPC 27/12	IPC 92	HRI 1981	SURVEY 1979	NOTE 12/1/94	12/1/91
29	NGC 1097	z=.0043	22.7	21.8	13.7	23.9	17.8	
18	QSO#27	z=.53	3.4	2.6	3.2	4.7	1.6	
10	QSO#28	z=.34	2.9	3.1	–	–	3.1	(1)
8	QSO#26	z=1.00	(.12)	2.6	3.6	4.9	(1.2)	(2)

Note (1) On the survey QSO #28 is merged with #29. Together they have a flux of 4.7. Taking #29 from the IPC measure as 1.6 leaves 3.1 for QSO #28.
Note (2) Because QSO #26 is so faint at the time of the PSPC observations, its hardness ratio is probably underestimated, making its conversion to F_X too low by about a factor of 2 for the measures in parenthesis.

(SASS counts can be approximately converted to counts in the $B = 0.4$ to 2.4 keV energy band in Table 1 by means of:

$$B = \frac{SASScts}{2}(1 + HR1).$$

Flux can then obtained by multiplying by an energy conversion factor,

$$\text{in this case,} \quad ECF = 1ct. = 1.4 \times 10^{-11} ergcm^{-2} \qquad \text{for PSPC}$$

and these flux values were used in Table 2.)

In order to compare to the average flux counts of sources in high latitude control fields, however, the same detection program and energy conversion factor of $ECF = 1.14 \times 10^{-11} cgs$ used in the 0.5 to 2.0 keV band by Hasinger et al. (1993) was applied to the NGC 1097, PSPC exposure (see Radecke 1996). The resulting log $N(> S)$ counts are shown in Fig.4 where the normal background counts are represented by a dashed line. For the three brightest sources the over density is about a factor of 6 and stays significant all the way to $F_X = 0.2 \times 10^{-13} cgs$. Within $20'$ of NGC 1097 there are of the order of 10 excess sources. This presupposes, however, a normal background of sources and we should consider how a gaseous disk in NGC 1097 might obscure X-ray sources behind it.

For the average absorption of the disk in NGC 1097 found in section 2.22 we calculate $\bar{N_H} = 0.6 \times 10^{21} cm^{-2}$. In the hard band, 0.5-2.0 keV this should only lower intensities by around 10%. In places, however, there is indication of much denser H_H and it cannot be ruled out that heavier absorption could suppress background sources considerably, yielding a greater excess of sources which belong to NGC 1097.

2.2 Absorption by NGC 1097

Fig 3 shows the PSPC X-ray sources around NGC 1097 down to a level of $\sim 1 \times 10^{-3} cts^{-1}$ in the hard (.7–2.4 keV) band. It is clear all the strong X-ray sources fall north of the galaxy and all the weak sources fall south of the galaxy. (It should be remembered that normally QSO # 26 is among the brightest sources near NGC

1097 but, exceptionally, is not even seen at the deeper level of Fig.5 at this particular epoch.) This means that 7 bright sources fall north of NGC 1097 and 8 fainter ones fall south. It is striking to note the almost complete segregation of these sources.

The model which immediately suggests itself is that sources of equal brightness are grouped around NGC 1097 but that there is a disk of absorbing material which is tilted toward us on the south side and obscures most of the sources in that half. Can this be checked? Yes, there are several ways. One is to look at optical photographs of the spiral galaxy. It is clear from the CTI, 4 meter 103a-o plates that absorption filaments are seen silhouetted against the bulge on the SW side and that there is a softer haze of an overlying bulge on the NE side. Clearly the SW side is the side of the disk that is nearest the observer.

NGC 1097, being a barred spiral, it is difficult to be certain of the position angle of the major axis. But it is probably between $280° < p.a. < 310°$. If we take the mean direction between the two northern jets as the minor axis at p.a. $= 32°$ then the position of the major axis should be about p.a. $\approx 302°$.

Again, because of the barred nature of the spiral there is nothing we can assume to be circular, so we cannot judge the angle of inclination of the disk from the flattening of the optical isophotes. But if we assume an average angle of tilt of a disk toward us, 45○, then 75% of the volume around the galaxy would be obscured on the SSW side and only 25% on the NNE side. Further, if the X-ray sources are concentrated along the minor axes, then 100% could be clear on the NNE side and 100% obscured on the SSW side. We see that the probable geometry of an absorbing disk in NGC 1097 could explain the observations pictured in Fig.3 in a qualitative way.

The question now becomes, is there evidence of absorption in the X-ray spectra of the fainter sources? As Fig.6 shows, the fainter sources definitely average harder in spectral ratio than the brighter sources. This is as would be expected if neutral hydrogen in the outer part of a spiral disk were absorbing the X-rays from sources behind it. The soft energy band (A = .11 to .45 keV) would be absorbed more than the hard band (B = .52 to 2.01 keV) thus causing the hardness ratio, HR1 ($HR1 = \frac{B-A}{B+A}$) to approach its limit of +1. The X-ray sources on the SSW side of NGC 1097 (filled circles) are clearly harder than on the NNE side. They are also much harder than X-ray sources found in average PSPC fields. All this would imply that the X-ray sources on the SSW side of NGC 1097 were being obscured by gas in the disk of the spiral which was tilted toward the observer on this side. One notices, however, that the harder sources are about a factor of 10 fainter than the brighter ones. Table 4 shows the reduction in SASS measured intensities by absorption for increasing amounts of N_H and the resultant hardening of the spectrum because of the stronger absorption of the soft X-ray component. These absorption-hardening tracks are plotted as dashed lines in Fig.6.

Fig.6 demonstrates that the brighter X-ray sources cannot be absorbed by normal N_H in NGC 1097 in such a way as to resemble the fainter source because they would move into an unpopulated region of hardness. The fainter sources must be intrinsically fainter and be principally situated in the SSW side of NGC 1097 whereas the set of brighter sources located on the NNE side must be intrinsically brighter.

That being said, there is still clear evidence in Figure 6 that there is absorption and hardening of sources on both sides of NGC 1097. On the NNE side the absorption appears to distribute sources of similar hardness ratio from $-.6 < HR1 < .2$ (the brightest sources close to NGC 1097) and on the south side from $-.2 < HR1 \lesssim 1$. This behaviour would support the interpretation that the hydrogen disk in NGC 1097 is tilted toward us on the SSW side.

That this hydrogen gas must extend well beyond the optical limits of the galaxy is clear from the location of the X-ray sources with respect to the extent of the galaxy as shown in Fig.1. HI is generally detected further out in the disks of galaxies than the detectable limits of optical surface brightness. How far the HI disk extends in the unusual galaxy NGC 1097 would require a 21 cm radio map to determine. There is, however, optical evidence for a large extent of absorption around NGC 1097.

2.21 Optical reddening in NGC 1097

Because of an unusual situation pertaining in NGC 1097 it is possible to say where optical reddening material beyond the optical disk of the galaxy is located. The true color photograph in Fig.1 shows that the optical jets to NNE are relatively bright and relatively blue. But on the SSW side they are much fainter and distinctly redder. This is what one would expect if there were dust intermixed with the HI disk. The apparent reddening and obscuration of the SSW optical jets takes place in the same region where the apparent absorption and hardening of the X-ray sources takes place (from about $r = 3'$ where the optical disk stops to past $\sim 12'$ where the optical jets and X-ray sources are located). Therefore both the X-ray and the optical jet results supports a model for the spiral galaxy where an absorbing disk extends for outside the optical confines.

2.22 Absorption in NGC 1097 compared to other spiral galaxies

Because Fig.5 indicates on the SSW side of NGC 1097 mostly X-ray sources which are behind the disk, we can calculate what the average N_H is for the disk. From Fig.6 (lower dashed curve) and Table 4 that appears to range between $.15 < N_H < 1.2 \times 10^{21} cm^{-2}$ with an estimated mean about $N_H \approx .60$. By means of the relation $A_V = 0.56 N_H (10^{21} cm^{-2}) + 0.23$ developed by Predehl and Schmitt (1994) we can compute the visual absorptions expected for a mixture of gases which normally comprise a given N_H. They are listed in Table 4.

Table 4

Absorption-Hardness Tracks as a Function of N_H

Point	N_H	Inten.	HR1	Inten.	HR1	Av
1	$.15 \times 10^{21}$	1	-.6	1	-.2	.31
2	.30	.63	-.38	.72	.10	.40
3	.60	.32	.20	.47	.60	.57
4	.90	.22	.66	.39	.86	.73
5	1.20	.12	.88	.36	.96	.90
6	10	.06	~ 1	.12	~ 1	5.8

For the mean $N_H = 0.6 \times 10^{21} cm^{-2}$ estimated here for the sources absorbed by the NGC 1097 disk the calculated A_V is about 0.6 mag. That would predict a mean reddening of $E_{B_V} \sim 0.2$. The reddening of the optical jets in the SSW side of NGC

1097 in Fig.1 seems greater than this but one should consider that the optical jets are of very low surface brightness and the nonlinearity of the photographic plates at low intensity could amplify color differences. Sources not detected, however, could be absorbed much more, making our $\bar{N_H} = 0.6 \times 10^{21} cgs$ a lower limit.

HI profiles of samples of spiral galaxies (Bosma 1978) imply densities of $N_H \sim 0.2 \times 10^{21} cm^{-2}$ out to several times de Vaucouleur's (RC2) radii (Disney, Davies and Phillipps 1989). Since the de Vaucouleur's radius for NGC 1097 is $R_{25} = 4\farcm7$, we would expect this order of N_H out to around $9'$ to $14'$. This brings us out into the region of the absorbed and reddened optical jets (about $12'$) and the region of the absorbed and hardened X-ray sources ($\leq 18'$).

Of course, NGC1097 is an unusually active starburst galaxy with infared and radio properties that imply unusually large amounts of dust and absorption (Telesco, Dressel and Wolstencroft 1993). For regions near the nuclear ring, absorptions of $0.6 < A_V < 3.0$ were found (Hummel, van der Hulst and Keel 1987). Such heavy absorption near the center of a spiral is particularly unusual in view of the indications of generally smaller observations near the centers of spiral galaxies (Simien, Morenas and Valentijn 1993).

But the X-ray observations displayed in Fig.6 indicate that very strong absorption patches occur rather far out in the disk of NGC 1097 as well as in the central ring area. The hardest eight sources in Fig.6 indicate, from Table 4, absorption from $A_V = 0.9 mag.$ up to almost $A_V = 6 mag.$! Decrements of Balmer emission lines in the nuclear ring indicate absorptions of $0.85 < A_V < 3.5 mag.$ (Hummel, van der Hulst and Keel 1987). But in the X-rays we see evidence for even greater absorption out at distances of 7 to $13'$ from the nucleus. It is perhaps significant to note that four of the hardest X-ray sources in Fig.5, nos. 19, 25, 32 and 38, stretch out approximately along the line of the bar in NGC 1097. In optical photographs, along that bar very opaque filamentary absorption is conspicuous.

Overall, NGC 1097 is clearly a spiral galaxy which contains an unusually extensive disk of HI. The average opacity of that disk is also unusually large (see egs. Valentijn 1990 for opacities in other spirals). But in small regions the absorption can become extremely large. To date there seems to have been no high resolution HI mapping of NGC 1097. In view of the results accumulating on this very active Seyfert galaxy it would seem to be of great interest to obtain such an HI map at, for example, VLA resolution and sensitivity. The possible nature of some of these absorbed sources will be discussed in the last section of this paper.

2.3 Alignments of X-ray sources across NGC 1097.

Fig.5, which registers sources about twice as faint as in Fig.3, shows some interesting alignments for the harder sources. First there is the apparent alignment of hard sources (nos. 38, 36, 34, 32, 25, 19, 15) at about p.a. = 310deg (four sources on the SE side, three on the NE line). Secondly there are two sources on a line almost due north of NGC 1097 (nos. 9 and 16) and, almost exactly aligned across NGC 1097 to the south, two brighter, softer sources (nos. 39 and 41). These latter four sources act as if they were aligned more closely to the observer's line of sight than the absorbing layer on the SSW of the galaxy. They would then represent a minority of sources which were oriented such that they are clear on the SSW side and absorbed on the NNE side. This pairing and alignment of X-ray sources across galaxy nuclei is supported by ROSAT observations of five other active galaxies (Arp 1996a). It is also supported by the HRI observations of NGC 1097 which show evidence of narrower alignments of sources in various directions and which will be discussed in section 3.

2.31 The quasar #23 and the X-ray source no. 14

One interesting region in PSPC is shown in Fig. 7. PSPC source no. 12 is a quasar of $z = .89$ (#23 in Arp, Wolstencroft and He 1984) and near it is a strong source no. 14. The broad energy band pictured in Fig.7 shows there is a source, no. 13, located between nos. 12 and 14. In fact, the three sources seem linked together by an irregular bridge of X-rays. It would be important to study these sources with deep imaging in other wavelengths in order to investigate what they might be and whether they are associated. In section 3.2 we see the HRI identifies PSPC no. 14 with a probable quasar.

3. HRI Observations

About one year after the PSCP observations of NGC 1097 a comparable exposure of 9489s was obtained with the higher resolution but less sensitive HRI. The most noticable feature of this exposure as shown in Figures 8 and 9 and Table 2 was that QSO #26 was in its brightest recorded X-ray intensity. The field of the HRI was not large enough to encompass QSO #28, so aside from NGC 1097, Figs. 8 and 9 are dominated by the two bright quasars #26 and #27.

3.1 Extended X-ray Material?

The low surface brightness material detected by the variable filter smoothing, which is shown in Fig.8 was very much of a mystery because there was no trace of such material in the PSPC observations. Despite a higher sensitivity (by a factor of 2 to 3) and a lower noise CCD detector, the PSPC in comparable exposure time showed no traces of the extended structure which was seen on the HRI. The extended material seen on the HRI looked particularly real because it was well above the noise and was situated in the region of most intense activity between the strong optical jets and the bright quasars.

The solution to this puzzle apparently lies in the ultraviolet leak of the HRI filter. Tests on the ultraviolet bright star Vega shows a strong peak in the first three pulse height channels (David et al. 1993). But the background X-ray spectrum peaks in channels 4 to 12. Processing channels 1 to 3 of the NGC 1097 observations here showed a distinctly different picture than channels 4 to 12. Comparing Figs. 9 and 10 demonstrates that the region between NGC 1097 and the bright quasars is empty in true X-rays and filled with material in the ultraviolet sensitive channels. Further details on this 1500-1700Åultraviolet leak in the HRI are published in Arp (1995a).

Because this ultraviolet emitting material is filamentary and patchy it would not be expected to be continuum radiation from hot gas. It would rather be expected to be emission lines from recombinant radiation. As such it might be CIV 1549 or perhaps the longer lived forbidden lines [NeIV] 1602, [NeV] 1575 or the semiforbidden line OIII] 1663. The ultraviolet emission in Fig.9 reminds one of the networks of extended gaseous emission features seen in Per A (Lynds, 1970). But, of course, the features north of NGC 1097 would have to be analyzed spectroscopically before identification could be made.

Whatever the eventual identification, however, the placement of the ultraviolet features between the strongest optical jets emerging northward from NGC 1097 appears significant. As Fig. 8 shows, the ultraviolet emitting material extends from the active galaxy, out between the jets and ultimately involves the brightest quasars, #26 and #27. It would seem highly improbable that these bright quasars existed accidentally at just this position between the optical jets and that, further, the extended ultraviolet emission just accidentally stretched from the active galaxy nucleus out to this region of jets and quasars. Particularly compelling is the pure ultraviolet image of Fig.9. There we see the filamentary nature of the ultraviolet emission and that *the major filaments point toward the quasars.*

One interesting comment on the ultraviolet emission is that it occurs in that region NNE of NGC 1097 which we found in previous sections to be in front of the absorbing disk of NGC 1097 and the most free of absorption. In far ultraviolet wavelengths absorption is a high multiple of reddening (E_{B-V}), therefore comparable ultraviolet emission behind the disk of NGC 1097 on the SSE side would be expected to be strongly obscured. It is quite possible then that the ultraviolet emission could be associated with bipolar ejection or beaming from the nucleus of NGC 1097.

3.2 Point sources in HRI

Aside from the two strong quasars in Fig.8 there are only two other sources which appear compact. They are approximately aligned across NGC 1097. The NE one is no.6 in the SASS detected source list in Table 5 and is at p.a. $= 52°$ from NGC 1097. The SE one, called a in Fig.8, has $0.5 ctss^{-1} \times 10^{-3}$, about a factor of 2 below the lower limit of Table 5, and is at p.a. $= 239°$ from NGC 1097. On the U.K. schmidt IIIa-J plate of this region there is only one possible optical candidate, $22''$ N of the HRI X-ray position of no.6, at 02/47/12.6-30/07/02. It is at $m_J = 22.1 mag.$ and of uncertain color. On the other hand HRI No. 15 N (see Fig.11) falls only $1.''5$ from a 19.3 mag. stellar object and is a good candidate to be a new, additional quasar north of NGC 1097.

In Fig.11a maximum resolution image is presented which covers most of the HRI field. All 12 SASS cources listed in Table 5 are labelled except for nos. 2 and 3 which are too close to NGC 1097 to be resolved at this scale (see Fig.13) and no. 14 which is just outside the eastern frame and $4.'7$ south of no.7. Most interesting is no. 18 which is not a point source as shown by the fact that it was deleted only when scanned with the largest, $48'' \times 48''$ and $72'' \times 72''$ detect calls. It is, in fact, a condensation in the ultraviolet filament that points to the quasar #26 (in Fig.9). This ultraviolet patch, no. 18, also coincides closely with circular, optical terminus of a major optical ray (which can be seen in Figs. 1, 2 and 15).

Table 5

HRI sources found by SASS

No.	R.A. (2000)	Dec.	off axis	net $ctss^{-1} \times 10^3$	Remarks
1	2^hm^{m}19^{s}07	-30deg16$'$28.0	0$'$.7	44.2	NGC 1097
2	2 46 19.95	-30 16 00.0	.6	6.3	
3	2 46 21.01	-30 16 40.9	.6	6.1	
4	2 46 45.67	-30 00 48.5	16.3	9.1	QSO#26 z = 1.00
5	2 46 49.91	-30 07 39.5	10.6	8.7	QSO#27 z = .53
6	2 47 12.58	-30 07 24.1	14.1	1.2	
7	2 47 33.65	-30 11 10.4	16.4	7.4	
8	2 44 57.80	-30 15 25.5	18.1	4.6	
9	2 46 02.85	-30 03 09.6	13.8	2.4	QSO#23 z = .89
14	2 47 44.00	-30 14 54.5	17.8	13.3	
15	2 45 47.54	-30 05 01.7	13.5	2.3	
18	2 46 25.90	-30 07 30.2	8.8	1.9	

3.3 A z = 3.09 X-ray quasar which was not detected by ROSAT

Because of the implication that many of the optically unidentified X-ray sources are faint apparent magnitude, high redshift quasars it is important to examine the status of a z = 3.09 quasar (#25) discovered near the strong optical jets by Wolstencroft et al. (1983). Although the quasar was listed as $V_{5000} = 19.3 mag.$ when measured (Arp, Wolstencroft and He 1984), actually on most of the plates it was near the plate limit, i.e. fainter than 20^{th} mag. It is interesting that it was not detected in the present PSPC or HRI X-ray observations although it was discovered by its X-ray emissions as measured by the Einstein Laboratory. This could be because the quasar was in a bright phase at the time of Einstein observations or because the spectrum is harder and was detected because of Einstein sensitivity to harder X-ray spectra.

But what is certain is that this z = 3.09 quasar was descovered in the clearest patch near NGC 1097, just between the two strongest optical jets where the brighter, lower redshift quasars are situated and where X-ray absorption is at a minimum and the ultraviolet 1500-1700Å features are strongest. Everywhere else within the 20$'$ radius studied in the PSPC observations, there was, as we have discussed, moderate to heavy absorption.

This strongly suggests that if the z = 3.09 quasar was located at any other azimuth it would not have been discovered. And this then supports the inference that many of the numerous X-ray sources surrounding NGC 1097 are optically fainter, higher redshift quasars. Because starting at z = 2 higher redshifts become increasingly red, this is reason in addition to the expected absorption, to search for optical identifications of the X-ray sources in the red or far red.

3.5 HRI Observations south of the nucleus

Fig. 12 shows a higher resolution image of NGC 1097 in a region reaching $\sim 12'$ south. The major X-ray protuberance from the nucleus is broad and in the direction of the nearest bright quasars, i.e NNE between the brightest optical jets. There is a line of three or four sources to the SW at p.a. ≈ 245 deg. That is near the backward extension of the dog leg jet at p.a. $= 230$ deg.

But most clearly shown in Fig.12 is a string of about six small X-ray sources extending almost due south of NGC 1097 at p.a. $= 183$ deg. This string includes two

PSPC X-ray sources (PSPC nos. 39 and 41) which were part of a line of PSPC sources (with nos. 9 and 16 on the north side) across NGC 1097 which were noted in Fig.5 and discussed in section 2.3. In Fig.12 two of the sources which fall to the left of this line (at p.a. = 173 deg) are ultraviolet and/or soft X-ray sources as adduced from their strength in channels 1–3. This remaining line of 4 sources originating from NGC 1097 at p.a. = 183 deg therefore is an accurate line of moderately hard X-ray sources which adds to and confirms a line found with the PSPC.

The sources shown in Fig.12 were not strong enough to be among the SASS detected sources in HRI as listed in Table 5. However, just viewed as a distribution of HRI photons southward from NGC 1097, they serve to confirm the previously detected line of PSPC sources.

This line of X-ray sources is closely (within 12deg) of the direction of the most northern optical ray but definitely slightly outside the "cone" of the two major optical jets. The summary of the PSPC and HRI observations so far must be that there are a number of narrow, straight lines of point X-ray sources emerging from the nucleus of NGC 1097. Some can be directed along the major axis but most are concentrated within, or near, an angle or cone, which is defined by the optical jets and is roughly along the direction of the minor axis.

3.6 Highest resolution of the nucleus of NGC 1097

Figures 13a, b and c show the highest resolution obtainable with the HRI. Image pixels of 1×1 arc sec have been smoothed with a gaussian of 2.1 giving a FWHM of $4\overset{''}{.}9$. Since the HRI can put about 50% of its light inside a 6 arc sec circle this slightly under smooths the data.

Fig. 13a, at top, shows the resolved sources within about 2 arc min of the nucleus coming off mainly within the cone of the optical jets (dashed lines to NE). There is also an extension of emission to the SW at p.a. 125 deg −305 deg. This is in the direction of the line of hard PSPC sources discribed in section 2.3 at p.a. = 130 deg = 310 deg.

It is interesting to note the decomposition into ultraviolet sensitive (channels 1-3) and pure X-rays (channels 4-10) presented in Fig. 13b and c. The ultraviolet and/or soft X-ray sensitive channels in Fig. 13c are clearly absorbed on the SW side of the nucleus where the optical photographs show overlying absorption. Channels 1-3 also show extensions and sources going up in the direction of optical ray1, where we saw in the PSPC discussion there was the least gaseous absorption.

On the other hand the pure X-ray channels in Fig. 13b show filling out on the absorbed side of the nucleus and a spur going out along the direction of the line of hard PSPC sources at p.a. = 130 deg −310 deg. It would seem the channel division in the HRI is confirmed in its ability to separate the softer radiation from the harder X-rays.

It would also suggest that these are material ejections or beams of high energy radiation coming out along the minor axes which fluoresce gaseous clouds and generate clouds of uv emission. Similar optical emission is found particularly along radio ejection paths in active galaxies such as Cen A (ESO 1989). In NGC 1097, however, this ultraviolet emission appears strongly absorbed on the SSW (near side) of NGC 1097.

4.0 Survey observations of NGC 1097.

The ROSAT Survey covered the general region of NGC 1097 with a summed exposure of $\sim$ 400 sec. One of the advantages of consulting these observations is that one can look as distant from the central object as wished without having to deal with exposure corrections, or field distortions. For this study a $4 \times 4°$ square around NGC 1097 was examined. Fig. 14 shows the $2.5 \times 2.5°$ region which appeared the most interesting. It reaches a flux level slightly fainter than $F_x = \lesssim 4.0 erg cm^{-2} s^{-1}$ in the broad, $.1 < keV < 2.4$, band.

The striking feature in the large region is the apparent string of three bright X-ray sources reaching in a SW direction from NGC 1097. The two weaker sources do not seem to be identified with any SRC schmidt ($\lesssim 23 mag.$) optical objects but the third, which is very strong at $0.5 ctss^{-1}$ in the $0.1 < keV < 2.4$ band, is accurately identified with a 16.5 mag., compact blue object (marked A in Fig.14). Its position from the schmidt plate (APM) is $02^h 38^m 32^s 4 - -31°17'00''$ (2000.0). On the SRC schmidt survey the candidate looks essentially stellar, possibly very slightly soft at the edges. A spectrum by A.P. Fairall at the Cape observatory shows a featureless blue continuum marking it as a BL Lac object.

What makes this object particularly interesting is that it is closely on a line opposite QSO# 28 which in turn is closely on a line with the brightest optical jet coming NE out of NGC 1097. This jet is sketched in Fig.15 and its extension in the opposite direction is indicated as dashed. BL Lac objects have been shown to be associated with low redshift Seyfert Galaxies (Arp 1996) at high significance. It would be interesting to obtain the redshift of the present example.

In Fig. 15 we have investigated a smaller region to a 2.4$\times$ deeper isophote level than in Fig.14. The three brightest quasars (# 's 26, 27 and 28) NE of NGC 1097 are visible as X-ray sources. Also the 19.5 mag. quasar candidate #8, identified from the schmidt objective prism study but never measured with slit spectra, is identified as a strong X-ray source SW of NGC 1097. It is interesting how the direction between NGC 1097 and candidate A now becomes preferentially populated with sources when this fainter level of X-rays is investigated. Fig.15 also shows a tendency for the sources SW of NGC 1097 to be elongated somewhat along this direction, particularly quasar candidate #8. *But the most significant association is demonstrated by QSO #28. There all the X-ray isophotes are elongated, in both directions, along the line passing through NGC 1097.* This is very closely the same direction as the strongest optical jet which, as Fig.15 shows, is situated just between QSO #28 and NGC 1097.

In fact Fig.15 is an approximate summary of the most important results of the preceding higher resolution PSPC and HRI data. Fig.15 emphasizes how tight the groping of the three bright quasars (which are the brightest of six X-ray quasars in this small region) and the Seyfert galaxy is, how the major optical jets lead from the active galaxy to the quasars, and how the outer X-ray isophotes of the galaxy and the brightest quasar demonstrate physical involvement of the quasars with NGC 1097.

5.0 Discussion and Summary.

One of the brightest, most active Seyfert galaxies in the sky is NGC 1097. Extra-ordinary optical jets were discovered coming from it in 1975. Then the first X-ray observations in 1983 showed that in the region of the jets bright X-ray sources were present. These were soon identified as quasars. In turn this led to a systematic optical search within $\lesssim 1\overset{\circ}{.}4$ of the galaxy which identified 31 quasars, most of which were statistically related to the galaxy.

Now ROSAT observations with PSPC, HRI and Survey identify excess numbers of new X-ray sources which are candidates for further quasars, some at large distances from NGC 1097 and many close in, within $20'$. For example the eight fainter X-ray sources south of NGC 1097 shown in Fig.3, all fall in an area about $1000'' \times 500'' = .04$ sq. deg. To this flux level only between one and two background objects would be expected. So the eight sources should belong, as their distribution suggests, to NGC 1097. If, as we have seen, there is evidence for very heavy N_H absorption in some parts of the NGC 1097 disk, then the expected background source count could be supressed appreciably and then a much larger percentage of the 36 X-ray sources within $\sim 20'$ in Table 1 would become members of NGC 1097.

Since six brighter associated X-ray sources in a small clear region between the optical jets have been identified as optically bright apparent magnitude quasars, plus now a probably 7th candidate, it is natural to suppose that the fainter associated X-ray sources could be identified as fainter apparent magnitude quasars. For quasars all at the same distance it has been shown that quasars of redshift $z \approx 2$ are several magnitudes fainter than quasars of $z \approx 1$ (Arp 1987). Since the brighter quasars associated with NGC 1097 have $.3 < z < 1.0$ and $18 < m_J < 20mag.$ we would expect the fainter quasars to have $1.5 < z < 3$ and $21 < m_J < 23mag.$

But to this we must add the average absorption, which in section 2.22 we found to be about $\bar{A}_V \approx 0.6mag.$ Therefore we would expect large numbers of quasars to be identified in the apparent magnitude range $22 < m_J < 24mag.$

Of course some of the X-ray sources, as shown in Fig.6, are extremely hard and faint suggesting absorptions from N_H that would imply optical absorptions of $0.9 < A_\nu < 6mag.$ If these were also quasars they might suggest a population of young objects in dust cocoons. Because of this implied range of dust absorption it would be necessary, and extremely rewarding, to use the new, large aperture telescopes with the most sensitive red and infrared detectors to explore optical identifications of these X-ray sources.

It would also be valuable to obtain a high resolution HI map of NGC 1097 with an instrument like the VLA. (Such has not been measured to date.) This observation would check the angular extent and thickness of this unusually strong absorption disk in NGC 1097. It would also reveal whether there were dense concentrations of HI coinciding with the apparently strongly absorbed X-ray sources.

Some coments on low and high redshift quasars which are interesting in the present context are:

1) High redshift quasars empirically have harder X-ray spectra: For $1.75 < z < 3$, $\overline{HR1} = -.09$ (Stewart et al, 1994). For quasars of low galactic N_H, between $2.81 < z < 4.11$, $\overline{HR1} = -.12$ (Bechthold et al. 1994). Looking at Fig.6 it is clear that the fainter set of X-ray sources starts at about this hardness ratio and runs along a hardening-absorption line until reaching apparently highly absorbed sources. This does not behave like a background of sources of varying apparent flux nor does it

act like sources of intrinsically different luminosity in NGC 1097. The observed behavior suggests one kind of source experiencing varying degrees of absorption within NGC 1097.

2) High redshift quasars associated with other nearby galaxies are fainter and more numerous than low redshift quasars. For example, M82 shows three quasars of $z \approx 2$ and $m_v \approx 20mag.$ emerging on a cone from its active nucleus. On the other side of M82 is a very strong X-ray source so far unidentified. (Arp 1987 p 160; Stock, Wurtz and Kühr 1991.) Situated on the HI arm leading from M81 to NGC 3077, however, is one quasar of $z = .77$ which is $m_v \approx 16mag.$ (Bi, Arp and Zimmermann 1994).
3) In general, high redshift quasars, being intrinsically fainter, can be seen only in a considerably smaller volume of space than $.3 < z < 1$ quasars and therefore must be more numerous than the latter. This is suggested to be the situation that we are observing in NGC 1097.

The potential rewards are therefore very great for further investigation of NGC 1097. With large telescopes it is possible that we could study the properties of a large number of quasars all at the same distance and their recent generation in what appears to be an extraordinary quasar factory. If they are not quasars, the same big telescope observations would be required to identify what they actually are. In view of the evidence discussed in the present paper it would appear that the conventional viewpoint has the obligation to demonstrate that they are *not* quasars.

Examining the distribution of the X-ray sources in and around NGC 1097 reveals a number of lines of sources through the galaxy nucleus. Most of these are within the "cone" of the optical jets although some seem to be at nearly right angles, or roughly along the inferred major axis. Precedent for approximately orthogonal lines are present in multiple lines of X-ray sources originating from active galaxies and AGN's was presented in a previous paper titled: "X-ray Observations of Five Galaxy-Quasar Pairs" (Arp 1996a,b).

These lines of smaller X-ray sources in NGC 1097, particularly within the main optical jets or cone, raises again the question of whether they represent finer "sub" ejections within a broader ejection of whether these are events which occur along lines which originate from the nucleus. In the latter case they might represent creation strings going through the nucleus or perhaps even radiation beams from the nucleus along which creation takes place. Deeper HRI X-ray exposures would help elucidate these possibilities.

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Figure Captions

Fig.1 Photographic plates in the red and the blue from the CTIO 4 meter telescope by Arp have been combined into a true color picture by Jean Lorre at the JPL Image Processing Laboratory. Note that the two optical jets coming SW from the galaxy are much weaker and redder than the ones coming NE.

Fig.2 Schematic representation of the optical jets and outer parts of the galaxy in white. The PSPC X-ray observations are in color and represent 5 arc sec image pixels smoothed x3. Note weak source NNW of right angle jet is normally among brightest in field.

Fig.3 All PSPC sources to a contour level of 0.18 cts per $5 \times 5''$ arc sec image pixel, gaussian smoothed x2, in 0.7-2.35 keV band. Note segregation of strong and weak sources and note one of the strongest sources on N side is missing because it is temporarily at a very low phase (see Table 2 and Fig.15).

Fig.4 The dashed line represents count density as a function of brightness for 27 representative sky fields as reported by Hasinger et al. (1993). The triangles represent counts of X-ray sources in the PSPC field of NGC 1097. The circle represents the normally brightest quasar on the field, #26.

Fig.5 All PSPC hard sources (.7-2.35 keV), $5 \times 5''$ image pixels gaussian smoothed x2 with lowest contour at 0.1 cts/image pixel. Numbers identify sources as listed in Table 1.

Fig.6 All sources within $20'$ of field center, standard analysis (SASS) soft plus hard band counts (A+B) plotted vs hardness ratio HR1 = B-A/A+B. Filled circles represent 8 sources on S side of NGC 1097 as shown in Fig.3. They are identified in Fig.5 (in order of hardness, no. 40, 41, 37, 39, 36, 34, 38, 32). The dashed lines show how sources are absorbed and hardened by increasing values of N_H as calculated in Table 4.

Fig.7 PSPC sources nos.12, 13 and 14 shown linked together by broad band X-ray radiation (.1 to 2.4 keV). No. 12 is a quasar of $z = .89$. No. 14 is a 19.3 mag. stellar candidate. Image pixels are $5 \times 5''$ smoothed gaussian 2 for FWHM=$24''$. Lowest contour is 0.17 photons/image pixel.

Fig.8 HRI observations of NGC 1097 with greater smoothing for lower surface brightness features. Quasars #26 and #27 are strong and situated NNE of the galaxy. Compact sources nos. 6 (Table 5) and source SW, no.a, are aligned across the NGC 1097 nucleus at p.a. = 52° and p.a. = 239°.

Fig.9 HRI of NGC 1097 using only PHA channels 1-3. Image pixels of $4''$ have been smoothed with a 8 gaussian to give $75''$ FWHM. Lowest contour level is at .085 cts per image pixel. Ultraviolet features have been marked A through F.

Fig.10 HRI of NGC 1097 using only PHA channels 4-12 for comparison with Fig.9– same smoothing with lowest contour at .15 cts per $4''$ image pixel.

Fig.11 The HRI field processed by the maximum resolution (maxresf) algorithm. Numbers represent sources identified by SASS and listed in Table 5.

Fig.12 The HRI field south of NGC 1097 with 4 arc sec image pixels smoothed by a $1 \times$ gaussian giving $9''$ FWHM. PSPC nos. 39 and 41 are part of a line of PSPC sources discussed in section 2.3.

13 Highest resolution reduction of HRI observations of NGC 1097 nucleus. Image pixels of $1 \times 1''$ have been smoothed with a gaussian of 2.1 giving FWHM = $4\farcs9$. Upper panel shows PHA channels 1-10 with minor axis optical cone drawn in dashed and approximate major axis indicated at orthogonal position. Sources nos. 2 and 3 are from Table 5. Lower left panel (b) shows PHA channels 4-10 and lower right (c) channels 1-3. Note different character of sources coming NNE out of nucleus and absorption on SW side in the soft X-ray and/or ultraviolet channels.
Fig.14 Survey ROSAT data over $2\fdg5\times$ $2\fdg5$ area around NGC 1097. Note string of 5 strong X-ray sources of which NGC 1097 is a member and that this alignment is approximately along line of the strongest optical jet – and its backward extension (shown dashed). Image pixels are $57'' \times 57''$ smoothed by a 2 sigma gaussian filter $= 268''$ FWHM in the $.1 < keV < 2.4$, broad energy bands. Lowest contour is 0.6 photons/image pixel.
Fig.15 Magnifed version of Fig.14 with lowest contour at 0.25 photons/image pixel. Bright quasars (#'s 26, 27, 28) and quasar candidate (# 8) are marked. Lines and shaded patch represent optical jets to NE and dashed extension backward. Full line cone to SW indicates sources leading toward the BL Lac object marked A in Fig.14.