THE ASTROPHYSICAL JOURNAL, 508:L000–L000, 1998 November 20
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# DISCOVERY OF A NUCLEAR X-RAY SOURCE IN NGC 7331: EVIDENCE FOR A MASSIVE BLACK HOLE

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*Received 1998 May 8; accepted 1998 August 3; published 1998 October 21*

## ABSTRACT

Using *ROSAT*, we have made the first deep X-ray observations of NGC 7331, discovering a nuclear X-ray source coincident with the previously determined radio and optical nuclear centers. The positions, luminosities, and fluxes of X-ray sources in the field are compared with previously identified radio and optical sources. The nucleus of NGC 7331 has been analyzed to discern any new evidence supporting the presence of a massive black hole, and comparisons are made with other low-ionization nuclear emission-line region (LINER) galaxies. The flux ratio of core radio to soft X-ray emission in NGC 7331 is lower than in other LINERs included in our sample.

*Subject headings:* galaxies: individual (NGC 7331, NGC 7335) — galaxies: nuclei — X-rays: galaxies

## 1. INTRODUCTION

Deep radio observations of NGC 7331 were first made in an attempt to search for the supernova remnant (SNR) from supernova 1959D (Cowan, Romanishin, & Branch 1994, hereafter CRB). Although the SNR was not identified in those observations, an unresolved nuclear source was detected (CRB). Optical observations of the nucleus of NGC 7331 identified an optical LINER spectrum (Keel 1983; Bower 1992). These two discoveries support the possibility that NGC 7331 harbors a massive black hole (MBH). Rubin et al. (1965) and Afanasiev, Silchenko, & Zasov (1989) made kinematic studies, measuring the rotational motion from [N II] and H$\alpha$ emission lines. Based on these observations, Afanasiev et al. (1989) suggested an MBH of $\sim 5 \times 10^8\ M_\odot$ in NGC 7331. Bower et al. (1993), however, suggested that this rotational motion could be explained by models without an MBH and with a constant mass-to-light ratio as a function of radius. Bower et al. (1993) were only able to exclude an MBH with a mass greater than $(5\text{–}10) \times 10^8\ M_\odot$ (CRB), a result which is relatively insensitive to small differences in the assumed distance to the galaxy. The Bower et al. (1993) mass limit is also near the upper limit of measured masses for massive dark objects found in LINER galaxies, which have X-ray and radio properties similar to those found in NGC 7331 (Ho 1998).

In this Letter, we report on the first deep *ROSAT* X-ray observations of NGC 7331 and their impact in understanding the nature of NGC 7331's LINER nucleus. In § 2, we discuss the results of the observations and the techniques used to reduce these data. Classically, the possible indicators for an MBH are the detection of an unresolved nuclear source, a nonthermal radio and X-ray spectral index, variability in the nuclear flux over months to years, and an anticorrelation between X-ray and radio variability (Melia 1992). The fact that NGC 7331 possesses an unresolved nuclear source and has a nonthermal radio spectral index was confirmed by CRB. This Letter identifies a similarly unresolved X-ray source but can make no statement as to the nature of the X-ray spectra. The confirmation of a nonthermal X-ray spectra and the last two criteria for an MBH requires further X-ray and radio observations. While starburst galaxies can also have nonthermal, unresolved sources, there is no evidence for an anticorrelation in X-ray and radio variability in such galaxies. Other indicators of the presence of an MBH in NGC 7331 will be discussed in § 3 of this Letter. Also in § 3, we will provide comparisons of our results with current theories and observations of low-luminosity active galactic nucleus (LLAGN)–powered LINERs and make our conclusions.

## 2. OBSERVATIONS AND DATA REDUCTION

NGC 7331 is an Sbc spiral galaxy, which was observed with the *ROSAT* high-resolution imager (HRI) in 1995 December to study the nuclear source that had been previously observed in the radio with the Very Large Array (VLA)[1] (CRB). The HRI is an X-ray photon collector with no spectral resolution,

[1] The VLA is a facility of the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under contract with the National Science Foundation.

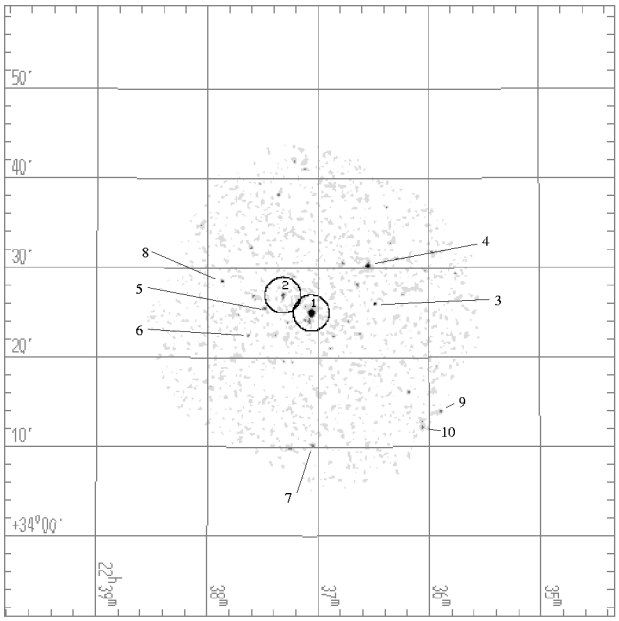


FIG. 1.—A gray-scale image of NGC 7331 and the field. NGC 7331 is the circled object labeled 1, and NGC 7335 is the circled object labeled 2. The X-ray detection of the nuclear source in NGC 7331 is within 5″.0 of prior radio observations of the nucleus given in Table 2. The remaining eight unidentified sources listed in Table 1 (3–10) are indicated in this figure.

TABLE 1
X-RAY SOURCES IN THE FIELD OF NGC 7331

| Source | R.A. (2000) | Decl. (2000) | Counts ($ks^{-1}$) | Flux ($10^{-13}$ ergs $s^{-1}$ $cm^{-2}$) | Comment |
|---|---|---|---|---|---|
| 1 ..... | 22 37 3.64 | +34 24 59.27 | 4.17 ± 0.4 | 41.3 ± 0.63 | NGC 7331 |
| 2 ..... | 22 37 1.86 | +34 26 53.90 | 1.3 ± 0.3 | 2.15 ± 0.36 | NGC 7335 |
| 3 ..... | 22 36 29.38 | +34 25 56.78 | 0.9 ± 0.3 | 1.49 ± 0.50 | |
| 4 ..... | 22 36 33.13 | +34 30 11.49 | 1.9 ± 0.4 | 3.16 ± 0.66 | |
| 5 ..... | 22 37 28.97 | +34 25 25.49 | 1.0 ± 0.3 | 1.66 ± 0.50 | |
| 6 ..... | 22 37 38.15 | +34 22 27.36 | 0.5 ± 0.3 | 0.83 ± 0.50 | |
| 7 ..... | 22 37 3.48 | +34 9 47.85 | 1.4 ± 0.7 | 2.33 ± 1.16 | |
| 8 ..... | 22 37 51.93 | +34 28 29.43 | 0.9 ± 0.4 | 1.49 ± 0.66 | |
| 9 ..... | 22 35 54.60 | +34 13 51.34 | 9.2 ± 0.9 | 15.3 ± 1.5 | |
| 10 ..... | 22 36 3.43 | +34 12 14.95 | 5.9 ± 0.9 | 9.80 ± 1.50 | |

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

collecting photons with energies ranging from 0.12 to 2.4 keV. The observations (see Fig. 1) were made over a 2 day period with a total observation time of 30.5 ks. The search was centered on the CRB radio center of NGC 7331 at R.A. (2000) = $22^h37^m4^s.8$, decl. (2000) = $+34°25'11''.5$.

Raw data reduction was provided by the *ROSAT* Standard Data Processing Center. Standard *ROSAT* tests for short-term variability are not applicable because of insufficient counts. The data were further reduced using the IRAF routine GAUSS, which convolved the data with a circularly symmetric Gaussian function, with the parameter $\sigma$ set to 1 pixel, effectively $8''.0$. The image was smoothed with a Gaussian because of concerns from the Data Processing Center that the standard analysis system was not very reliable in properly identifying sources in complex emission regions. Sources that were initially reported as individual point sources by the Center are actually part of a more complex X-ray emission region. The data were then evaluated with the NOAO-IRAF routine QPHOT to obtain object counts, count noise, and accurate position measurements. The aperture radius used to determine the count flux from the galaxy was set to $24''$, and sky background measurements were determined with the specified parameters of an inner annulus of $80''$ and an outer annulus of $102''$.

Lacking direct X-ray spectral data, a value for the log $N(\mathrm{H}) = 21.3$ (Burstein & Heiles 1984; van Steenberg & Shull 1988; Stark et al. 1992; Smith 1998) and photon indices, $\Gamma$ ($dF/dE \propto E^{-\Gamma}$), of 1.0 and 2.0 for the central sources in NGC 7331 were assumed in order to determine the unabsorbed X-ray flux. The total column density of hydrogen includes both the Galactic column density (Burstein & Heiles 1984) and the column density for the bulge of NGC 7331 (Smith 1998). The *ROSAT* HRI energy-to-count conversion factors were taken from the *ROSAT* Users Handbook, assuming a power-law spectrum. The assumption of an X-ray power-law spectrum is consistent with the possible presence of both an MBH and a post-starburst galaxy (Fabbiano 1996). The X-ray luminosity for the galaxy was calculated by assuming the distance to NGC 7331 as 15.1 Mpc (Hughes et al. 1998). The detections reported in Table 1 all meet at least a 3 $\sigma$ detection threshold. Since little is known about the other detected sources in Table 1, a power-law spectrum, a photon index of 1.0, and the same line-of-sight Galactic column density that was used for NGC 7331 were used to determine their energy flux measurements.

Sources of uncertainty in *ROSAT* positions include a known attitude solution error, which causes X-ray position offsets on the order of $6''$ (Zimmermann 1994). Since any correction would require knowing X-ray positions and since this is the first high-resolution image of the field, it is not possible to correct accurately for this error. In Table 2, we compare the optical, radio, and X-ray positions of the nucleus of NGC 7331. The values for the nuclear positions agree to well within $5''$ and are definitely coincident within the acceptable *ROSAT* error.

## 3. RESULTS AND DISCUSSION

The observations of the X-ray nuclear source in NGC 7331 support the likelihood of an MBH in its core. In Table 3, we compare the luminosity of the nuclear source in NGC 7331 with luminosity values for other LINER galaxies. The reported luminosities for two identified starburst galaxies are also included in this table for comparison.

An assumed power-law spectrum and photon indices of 1.0 and 2.0 were used to analyze our *ROSAT* observations of NGC 7331, because these are typical of other observed X-ray LINERs in the energy range from 0.1 to 2.4 keV. The X-ray luminosity of NGC 7331 in this bandpass region is within the observed range found in other LINERs and somewhat larger than those luminosities observed in typical starburst galaxies. We note that these LINER X-ray luminosities are near the upper limit of X-ray luminosities typically found in normal spiral galaxies (Fabbiano 1996), and therefore an X-ray luminosity cannot be used solely to identify possible MBHs.

The radio spectrum of a typical LLAGN is predicted to be powered by cylcosynchrotron emissions in the advection-

TABLE 2
NUCLEAR POSITIONS FOR NGC 7331

| Observation | R.A. (2000) | Decl. (2000) | Reference |
|---|---|---|---|
| X-ray ..... | 22 37 3.64 | +34 24 59.27 | This Letter |
| Radio ..... | 22 37 4.00 | +34 24 57.07 | CRB |
| Optical ..... | 22 37 4.01 | +34 24 56.07 | A. R. Klemola 1994, private communication |
| | 22 37 4.04 | +34 24 56.47 | Argyle & Clements 1990 |

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

TABLE 3
COMPARISONS OF NGC 7331 AND OTHER SIMILAR X-RAY SOURCES

| Source | Type (RC3) | Luminosity ($10^{40}$ ergs $s^{-1}$) | Photon Index | Bandpass (keV) | Mechanism | Reference |
|---|---|---|---|---|---|---|
| NGC 7331 ..... | SAab | 2.70–8.46 | $1.0 < \Gamma < 2.0$ | 0.1–2.4 | LINER | This Letter |
| NGC 4258 ..... | SABbc | 0.51 | 3.7 | 0.1–2.4 | LINER | 1 |
| NGC 4736 ..... | R SA(r)ab | 0.34 | 2.3 | 0.1–2.0 | LINER | 2 |
| NGC 4594 ..... | SAa | 5.3 | 1.80 | 0.5–2.0 | LINER | 3 |
| M51 ..... | SAbc | 2.5 | 1.76 | 0.5–2.0 | LINER | 3 |
| NGC 3079 ..... | SBc | 4.4 | 1.76 | 0.5–2.0 | LINER | 3 |
| M81 ..... | SAab | 1.2 | 1.9 | 0.5–2.0 | LINER | 3 |
| NGC 3642 ..... | SA(r)bc | 3.9 | 2.84 | 0.2–2.2 | LINER | 4 |
| NGC 3147 ..... | SA(r)bc | 24 | 1.74 | 0.5–2.0 | LINER | 3 |
| NGC 4579 ..... | SAB(rs)b | 28 | 1.87 | 0.5–2.0 | LINER | 3 |
| M33 ..... | SAcd | 0.1248 | 0.74 | 0.1–2.4 | Starburst | 5 |
| NGC 3628 ..... | SAb | <0.06–1.7 | 0.27–1.16 | 0.1–2.0 | Starburst | 6 |

REFERENCES.—(1) Pietsch et al. 1994; (2) Cui, Feldkhun, & Braun 1997; (3) Serlemitsos et al. 1996; (4) Koratkar et al. 1995; (5) Long et al. 1996; (6) Dahlem, Heckman, & Fabbiano 1995.

dominated accretion flow model used by Mahadevan (1997). The observed spectral index, $\alpha$, of $-0.6$ ($S_\nu \propto \nu^{+\alpha}$) for NGC 7331 indicates a nonthermal source powering the radio spectrum between 6 and 20 cm and is in agreement with observations of similar sources listed in Table 4. The value reported by CRB for the spectral index of NGC 7331 agrees closely with the theoretical value of the spectral index of M31, which was modeled with an MBH by Melia (1992). It should also be noted that this value of $\alpha$ is only slightly greater than the spectral index normally associated with SNRs, $-0.8$, and this might suggest a poststarburst nature (Condon 1996).

Table 4 also lists radio fluxes from other LINERs with identified nuclear radio sources. The same value of the spectral index found for NGC 7331 is reported for M51 and M81 by Turner & Ho (1994), and M81 has been confirmed to harbor an LLAGN by Ho, Filippenko, & Sargent (1996). While the CRB spectral index alone does not confirm the exact nature of the nuclear source in NGC 7331, it does suggest that NGC 7331 is an LLAGN, given the galaxy's identification as a LINER galaxy and the similarity of its spectral index to other LINER galaxies confirmed to harbor MBHs.

For a sample of LINER nuclei, Table 5 lists the ratios of soft X-ray and 6 cm radio fluxes. The X-ray fluxes listed in Table 5 are averaged over their stated bandpasses listed in Table 3. Among this limited sample, there appears to be a range for galaxies, from being relatively radio quiet (or X-ray loud) [log (X-ray/radio) $\propto -1.8$] to relatively radio loud (or X-ray quiet) [log (X-ray/radio) $\propto -4.6$]. It must be noted that this is a small sample and that these observations were taken at various epochs and with different instruments. (Radio observations are from the VLA and the Westerbork synthesis radio telescope, and X-ray observations are from *ROSAT* and *ASCA*.)

Another predicted indicator of an MBH is the bipolar outflow, which is believed to develop as the result of convective instabilities in the thin-disk approximation. This in turn leads to a quasi-spherical accretion flow, which is characteristic of the advective model (Narayan & Yi 1995). In the case of NGC 7331, these outflows have not been positively identified in any observations to date. If these features do exist, they are likely to extend only a few parsecs. For NGC 3079, a LINER galaxy 16 Mpc away, jets were identified that extended only 1.5 pc from the central engine (Trotter et al. 1998). Trotter et al. (1998) detected a molecular disk with a binding mass of $\sim 10^6\ M_\odot$. The radio observations of NGC 7331 indicate only a compact nuclear source with a ring of nonthermal sources extending beyond the optical galaxy (CRB). The fact that similar jets have not been detected in NGC 7331 can be attributed to the galaxy being 15.1 Mpc away ($1'' = 73$ pc), which makes the resolution of parsec-scale outflows beyond the capability of the CRB observations.

TABLE 4
CORE FLUX COMPARISONS OF NGC 7331 AND OTHER SIMILAR RADIO SOURCES

| Source (Type) | 2 cm (mJy) | 3.6 cm ($\mu$Jy) | 6 cm (mJy) | 20 cm (mJy) | Spectral Index | References |
|---|---|---|---|---|---|---|
| NGC 7331 ..... | ... | ... | 0.121 | 0.234 | −0.6 | 1 |
| (SAab) ..... | ... | ... | B array | A array | | |
| NCG 4258 ..... | 3.2 | ... | 2.4 | <10 | 0.4 | 2, 5 |
| | ... | ... | 1.5 | 2.0 | −0.2 | 3 |
| (SABbc) ..... | C array | ... | B array | A array (see references) | | |
| NCG 4579 ..... | ... | ... | ... | 40 | ... | 2 |
| (SAB(rs)b) ..... | ... | ... | ... | See references | | |
| NCG 4736 ..... | 3.2 | ... | 6.1 | 27 | −0.3 | 2, 5 |
| | 2.2 | ... | 3.6 | ... | −0.4 | 5 |
| (R SA(r)ab) ..... | C array | ... | B array | See references | | |
| M31 ..... | ... | 28, 39 | ... | ... | ... | 4 |
| (SA(s)b) ..... | ... | A array | ... | ... | | |
| M51 ..... | 2.3 | ... | 1.6 | ... | −0.6 | 5 |
| (SAbc) ..... | C array | ... | B array | ... | | |
| M81 ..... | 45 | ... | 92 | ... | −0.6 | 5 |
| (SAbc) ..... | C array | ... | B array | ... | | |

REFERENCES.—(1) CRB; (2) Hummel 1980 (Westerbork synthesis radio telescope); (3) Vila et al. 1990; (4) Crane, Dickel, & Cowan 1992 and Crane et al. 1993; (5) Turner & Ho 1994.

TABLE 5
SOFT X-RAY AND 6 cm RADIO FLUX RATIOS FOR SELECTED LINERS

| Source | Radio Flux[a] ($10^{-27}$) | X-Ray Flux[a] ($10^{-30}$) | log (X-Ray/Radio) | References |
|---|---|---|---|---|
| NGC 7331 ..... | 0.121 | 1.93–5.90 | −1.80 to −1.31 | This Letter, 1 |
| NGC 4258 ..... | 2.4 | 7.4 | −2.1 | 2, 3 |
| M51 ..... | 1.6 | 3.2 | −2.7 | 5, 6 |
| NGC 4736 ..... | 3.6 | 4.1 | −2.9 | 3, 4 |
| | 6.1 | 4.1 | −3.2 | 3, 4 |
| NGC 4579 ..... | 40 | 5.3 | −3.9 | 3, 6 |
| M81 ..... | 92 | 2.3 | −4.6 | 5, 6 |

REFERENCES.—(1) CRB; (2) Pietsch et al. 1994; (3) Hummel 1980; (4) Cui et al. 1997; (5) Turner & Ho 1994; (6) Serlemitsos et al. 1996.
[a] In units of ergs $s^{-1}$ $cm^{-2}$ $Hz^{-1}$.

Further evidence supporting the existence of a LINER nucleus in NGC 7331, similar to the one in M31, has been presented by Mediavilla et al. (1997) and further confirmed by Heckman (1996). M31 was identified as harboring an MBH of $3 \times 10^7 M_\odot$ by Kormendy & Richstone (1995). Mediavilla et al. (1997) and Ciardullo et al. (1988) report that the kinematics of the stars and ionized gas are decoupled, in NGC 7331 and M31, respectively. This is in contrast to the conditions found in Seyfert galaxies. Also, Tosaki & Shioya (1997) and Young & Scoville (1982) found no CO emission near the nuclei of NGC 7331 and M31. This is atypical for poststarburst galaxies. Their results do support the possibility that this absence of CO emission may be due to the presence of an MBH.

Also identified in the HRI image was a source that is within 9″ of the optical position of NGC 7335 (Klemola, Jones, & Hanson 1987). The observed flux was $2.15 \times 10^{-13}$ ergs $s^{-1}$ $cm^{-2}$ (assuming a power-law spectrum, a photon index of 1.0, and the same line-of-sight Galactic column density of hydrogen used in the previous section). If this X-ray source is associated with NGC 7335, this would indicate an X-ray luminosity of $3.1 \times 10^{41}$ ergs $s^{-1}$, assuming a distance to NGC 7335 of 110 Mpc ($z = 6315$ km $s^{-1}$ [de Vaucouleurs et al. 1991] and a Hubble constant of 55 km $s^{-1}$ $Mpc^{-1}$). Few observations have been made of this galaxy, and little is known about it. Based on this derived X-ray luminosity, however, this galaxy warrants further study in order to determine if it is also a possible candidate for AGN activity.

There are a number of tests associated with X-ray studies that could more definitively determine the nature of the nucleus of NGC 7331 (see, e.g., Fabbiano 1996; Serlemitsos, Ptak, & Yaqoob 1996; Nandra et al. 1997; Ho 1998). Such tests will require deep observations, which could provide a resolution of the spectrum at multiple wavelengths and identify any form of variability in the observed flux from NGC 7331.

The research was supported in part by NASA grant NAG5-3214 and has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. We thank an anonymous referee for helping us to improve this Letter.

REFERENCES

Afanasiev, V. I., Silchenko, O. K., & Zasov, A. V. 1989, A&A, 213, L9
Argyle, R. W., & Clements, E. D. 1990, Observatory, 110, 93
Bower, G. A. 1992, Ph.D. thesis, Univ. Michigan
Bower, G. A., Richstone, D. O., Bothum, G. D., & Heckman, T. M. 1993, ApJ, 402, 76
Burstein, D., & Heiles, C. 1984, ApJS, 54, 33
Ciardullo, R., Rubin, V., Jacoby, G. H., Ford, H. C., & Ford, W. K. 1988, AJ, 95, 438
Condon, J. J. 1996, in ASP Conf. Ser. 103, The Physics of LINERs, ed. M. Eracleous, A. Koratkar, C. Leitherer, & L. Ho (San Francisco: ASP), 132
Cowan, J. J., Romanishin, W., & Branch, D. 1994, ApJ, 436, L139 (CRB)
Crane, P. C., Cowan, J. J., Dickel, J. R., & Roberts, D. A. 1993, ApJ, 417, L61
Crane, P. C., Dickel, J. R., & Cowan, J. J. 1992, ApJ, 390, L9
Cui, W., Feldkhun, D., & Braun, R. 1997, ApJ, 477, 693
Dahlem, M., Heckman, T. M., & Fabbiano, G. 1995, ApJ, 442, L49
de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., Buta, R. J., Paturel, G., & Fouqué, P. 1991, Third Reference Catalogue of Bright Galaxies (New York: Springer) (RC3)
Fabbiano, G. 1996, in ASP Conf. Ser. 103, The Physics of LINERs, ed. M. Eracleous, A. Koratkar, C. Leitherer, & L. Ho (San Francisco: ASP), 56
Heckman, T. 1996, in ASP Conf. Ser. 103, The Physics of LINERs, ed. M. Eracleous, A. Koratkar, C. Leitherer, & L. Ho (San Francisco: ASP), 241
Ho, L. C. 1998, in Observational Evidence for Black Holes in the Universe, ed. S. K. Chakrabarti (Dordrecht: Kluwer), in press
Ho, L. C., Filippenko, A. V., & Sargent, W. L. W. 1996, ApJ 462, 18
Hughes, S. M. G., et al. 1998, ApJ, 501, 32
Hummel, E. 1980, A&AS, 41, 151
Keel, W. C. 1983, ApJ, 269, 466
Klemola, A. R., Jones, B. F., & Hanson, R. B. 1987, AJ, 94, 501
Koratkar, A., Deustus, S. E., Heckman, T., Filippenko, A. V., Ho, L. C., & Rao, M. 1995, ApJ, 440, 132
Kormendy, J., & Richstone, D. 1995, ARA&A, 33, 581
Long, K. S., Charles, P. A., Blair, W. P., & Gordon, S. M. 1996, ApJ, 466, 750
Mahadevan, R. 1997, ApJ, 477, 585
Mediavilla, E., Arribas, S., García-Lorenzo, B., & del Brugo, C. 1997, ApJ, 488, 682
Melia, F. 1992, ApJ, 398, L95
Nandra, K., George, I. M., Mushotzky, R. F., Turner, T. J., & Yaqoob, T. 1997, ApJ, 477, 602
Narayan, R., & Yi, I. 1995, ApJ, 444, 231
Pietsch, W., Volger, A., Jain, A., & Klein, U. 1994, A&A, 284, 386
Rubin, V. C., Burbidge, E. M., Burbidge, G. R., & Crampin, D. J. 1965, ApJ, 141, 759
Serlemitsos, P., Ptak, A., & Yaqoob, T. 1996, in ASP Conf. Ser. 103, The Physics of LINERs, ed. M. Eracleous, A. Koratkar, C. Leitherer, & L. Ho (San Francisco: ASP), 70
Smith, B. J. 1998, ApJ, 500, 181
Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R. A., Heiles, C., & Hurwitz, M. 1992, ApJS, 79, 77
Tosaki, T., & Shioya, Y. 1997, ApJ, 484, 664
Trotter, A. S., Greenhill, L. J., Moran, J. M., Reid, M. J., Irwin, J. A., & Lo, K. 1998, ApJ, 495, 740
Turner, J. L., & Ho, P. T. P. 1994, ApJ, 421, 122
van Steenberg, M. E., & Shull, J. M. 1988, in Proc. Celebratory Symp., A Decade of UV Astronomy with the *IUE* Satellite, Vol. 2, ed. E. J. Rolfe (Paris: ESA), 219
Vila, M. B., Pedlar, A., Davies, R. D., Hummel, E., & Axon, D. J. 1990, MNRAS, 242, 379
Young, J. S., & Scoville, N. 1982, ApJ, 260, L41
Zimmermann, H. U., ed. 1994, EXSAS User's Guide (Garching: MPE)