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NEW EVIDENCE FOR AN ANISOTROPIC RADIATION FIELD IN NGC 5252

M. ALMUDENA PRIETO[1] AND WOLFRAM FREUDLING[2]

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ABSTRACT

Observational evidence accumulated over the last decade strongly supports the idea that the ionizing radiation field in active galactic nuclei (AGNs) is anisotropic. Here we report on new evidence for this anisotropy in the particular case of the Seyfert 2 galaxy NGC 5252. H I observations of this galaxy reveal neutral gas surrounding the nucleus but located outside the bicone of ionized gas that notably characterizes this object. The neutral gas is at a distance from the nucleus where it could be reached by the ionizing radiation if this were isotropically distributed.

Subject headings: galaxies: active — galaxies: individual (NGC 5252) — galaxies: Seyfert — radio continuum: galaxies

1. INTRODUCTION

A currently favored paradigm for understanding the properties of AGNs requires the presence of an anisotropic radiation field originating from a central power source. The discovery of a broad line region in the polarized light spectrum of NGC 1068 by Antonucci & Miller (1985) provides one of the most clear indications that Seyfert 1 and Seyfert 2 galaxies are intrinsically the same. This observational result implies by itself an anisotropic radiation field. Evidence for anisotropy of the radiation has been found across the whole range of observed powers in AGNs, from the relatively low active Seyfert 2 galaxies (e.g., Wilson, Ward, & Haniff 1988) to the most powerful radio galaxies and quasars (Browne & Jackson 1992). Some of the more general arguments in support of this theory are the observed asymmetric ionized morphologies (e.g., Pogge 1989) and the derived nuclear photon deficit measured in some objects (e.g., Wilson et al. 1988; Kinney et al. 1991). However, these arguments are not definite proofs by themselves. Firstly, the computation of the photon deficit budget is based on the assumption of a given ionizing continuum, normally extrapolated from the optical or from the UV. In most cases, the derived ionizing continuum is strongly dependent on reddening assumptions. With regard to the observed morphology of the extended ionized gas, it may also be explained by an anisotropic distribution of the gas surrounding the nucleus of the AGN. This alternative explanation has not been excluded yet. Based on this later possibility we decided to investigate the presence and distribution of neutral gas in one of the most suggestive examples of radiation anisotropy in a Seyfert galaxy, NGC 5252.

NGC 5252 is an S0, Seyfert 2 galaxy at a redshift of 0.022. It is well known for its well defined biconical ionized structure revealed by images in the light of the [O III] 5007 Å emission line (Tadhunter & Tsvetanov 1989, hereafter TT). The sharpness of the biconical structure and the fact that no ionized gas is detected outside of the cone makes NGC 5252 one of the best illustrations for the anisotropic radiation theories of AGN. However, a similar ionization pattern could be produced if there were no gas outside the bicone structure to ionize.

In order to distinguish between the two alternatives, we mapped the atomic neutral hyrogen (H I) in NGC 5252. The galaxy was observed for 8 hr with the D configuration of the Very Large Array (VLA) at the National Radio Astronomical Observatory (NRAO) site near Socorro, NM.

2. RESULTS

2.1. H I *Distribution*

The results are presented in Figure 1. Figure 1*a* shows a contour map of the continuum emission near the redshifted H I line superposed on the [O III] 5007 Å image (TT). The contour map was created by averaging the line free channels of the VLA spectral line observations, which provided roughly 2 MHz bandwidth on either side of the line. The synthesized FWHM beam size was 38″ × 32″. Even with that low spatial resolution, the continuum emission appears elongated along the symmetry axis of the extended ionized gas. The center of the optical image is marked with a cross. The continuum emission has previously been mapped at 1400 MHz with a much higher angular resolution of ~1″ (Z. Tsvetanov 1992, private communication). This high-resolution map resolves the emission of the nucleus from that of a separate feature, the position of which is marked by a second cross to the north of the nucleus which confirms the position angle of the radio axis of ~170° reported by Unger et al. (1987).

A contour plot of the integrated H I flux is shown in Figure 1*b*, again superposed on the [O III] 5007 Å image of NGC 5252. The H I image was created by adding at each point in the image the flux from all frequency channels where line emission is present. Therefore, only positive fluxes are in this image. The noise of the data cube from which this map was created is ~1 mJy beam^{-1} per channel. Two main H I structures can be distinguished in the figure. One is elongated and extends along the E-W direction across the galaxy. The peaks of its distribution fills the regions outside the ionized biconical structure of NGC 5252. H I extends out to about 56″ (19 h^{-1} kpc, $H_0 = 100$ h km s^{-1} Mpc^{-1}) from the nucleus. The size is comparable to the maximum radius of the ionized gas, about 50″. The apparent displacement of the elongated H I structure with respect to the optical center may be an artifact due to the combination of low S/N and low spatial resolution in our maps. The H I

[1] ST-ECF, Karl-Schwarzschild-Strasse 2, D85748 Garching, Germany. Postal address: MPI fur Extrat. Physik, Gïessenbachstrasse, D85740 Garching, Germany.
E-mail:alm@rosat.mpe-garching.mpg.de
[2] European Southern Observatory, Karl-Schwarzschild-Strasse 2, D85748 Garching, Germany. Postal address: ST-ECF, Karl-Schwarzschild-Strasse 2, D85748 Garching, Germany.
E-mail:wfreudli@eso.arg.

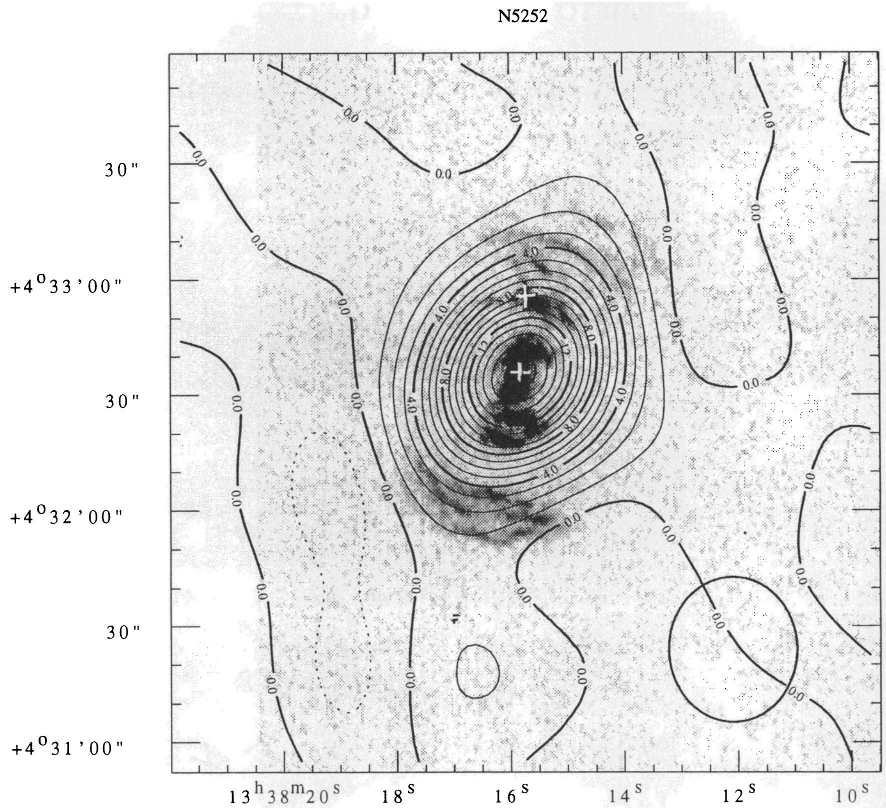

FIG. 1a

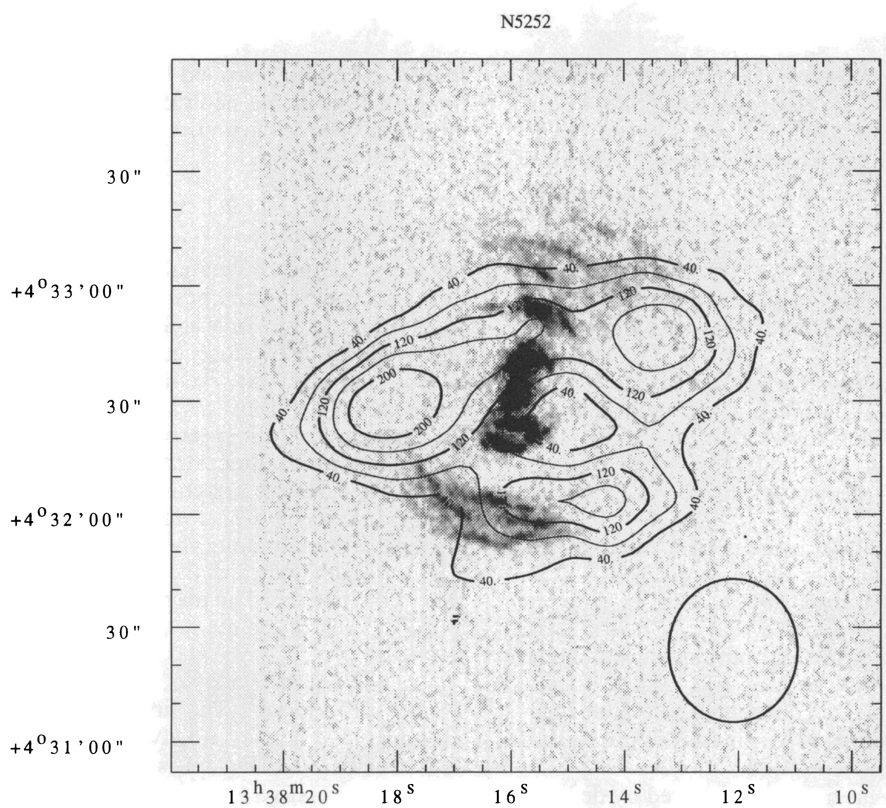

FIG. 1b

FIG. 1.—(a) Contour plot of the line-free continuum emission within a 5 MHz bandpass of the redshifted H I line. The levels of the contours are given in mJy per beam; dashed lines are negative contours. They are superposed on the [O III] 5007 Å image of NGC 5252 (Tadhunter & Tsvetanov 1989). (b) Integrated H I line contour plot superposed onto the [O III] 5007 Å gray-scale image of NGC 5252. The contour levels are given in mJy km s^{-1} per beam. (c) Contour plot of the optical continuum image (TT) of NGC 5252, in arbitrary logarithmic units, superimposed on a linear gray-scale representation of the integrated H I line image. The flux levels corresponding to the gray-scale can be taken from the contour plot of the H I image shown in Fig. 1b. In all panels, the size and orientation of the FWHM synthesized beam of the VLA observations are shown as ellipses in the bottom-right corner.

N5252

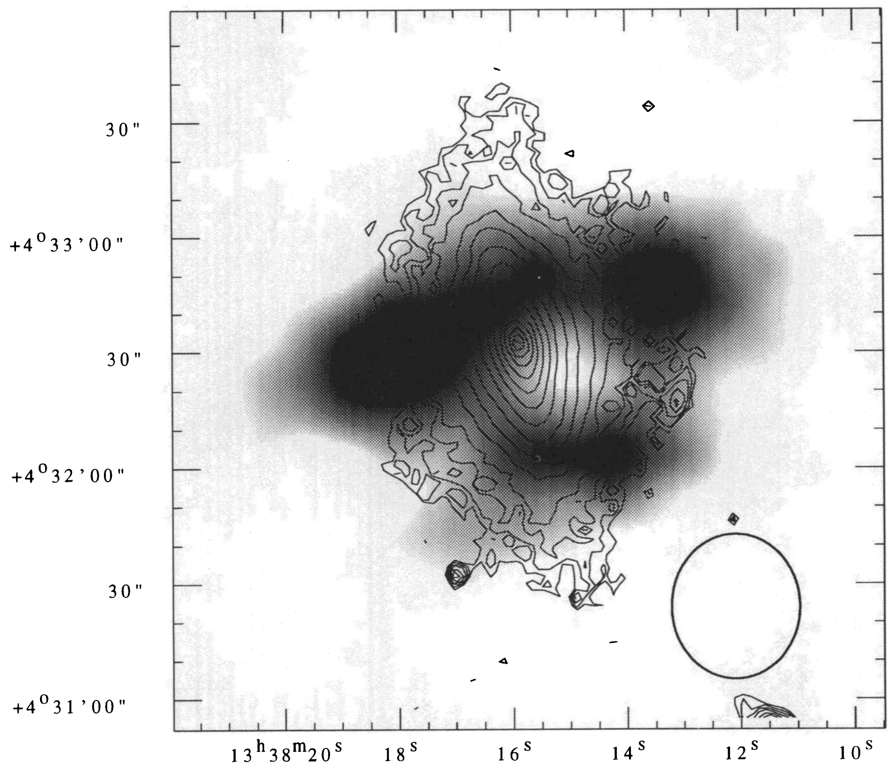

FIG. 1c

distribution appears depressed where it is close to the ionized gas and peaks at the edges of its elongated structure with a maximum integrated line flux of 240 mJy km s^{-1} $beam^{-1}$. The second discernible H I structure is an arclike feature of neutral gas about 15 h^{-1} kpc south of the nucleus. The feature could be a continuation of the ionized arc structure detected in the [O III] image. While the low angular resolution of the H I image cannot completely resolve the two structures, the image is consistent with them being two unconnected entities. This is also supported by the kinematics and is discussed in more detail in § 2.2.

The total integrated H I flux over the whole image is ~0.8 Jy km s^{-1}, in good agreement with a previously obtained single-dish spectrum at Arecibo. This shows that the VLA maps contain most of the H I gas, and that there is no smooth, overresolved component of the gas within the 3'.3 Arecibo beam.

The comparison of the radio with the optical observations reveals a complex interstellar medium around NGC 5252, dominated by neutral and ionized gas located in different sectors around the nucleus. We argue that the neutral gas, despite its location at similar distances from the nucleus as the ionized gas, is not ionized simply because it is located outside the radiation cone of NGC 5252. This conclusion is independent of the detailed distribution and kinematics of the neutral gas.

Thus, neutral and ionized gas may be connected by defining a ring or shell-like structure similar to those found in gas-rich S0 galaxies (van Woerden, van Driel, & Schwarz 1983; Prieur 1990). A certain level of support for this hypothesis is provided by the H I kinematics (see § 2.2). A more discriminatory test will be obtained in the near future with the VLA C array. The higher resolution provided by this array will be used to search for a pattern in the neutral gas similar to the series of shell structures seen in the ionized gas.

2.2. H I *Kinematics*

The investigation of the kinematics of the H I is severely hampered by the low spatial resolution of the current observations. Each synthesized beam contains a significant part of the total H I structure, for which therefore only the spatially averaged velocity distribution can be derived. The available information indicates an overall rotation. Held, Capaccioli, & Cappellaro (1992) investigated the kinematics of the ionized gas through long-slit spectroscopy at two position angles corresponding to the optical major axis and the radio axis, respectively. Their results are compared with the H I kinematics in Figure 2. Velocity measurements from Held et al. are coded as circles distributed along the two slit positions. The size of the circles roughly indicates the absolute value of the velocity relative to the nucleus. The maximum H I velocity amplitude measured at each of the main H I regions is indicated directly on the figure.

The half-width velocity of the integrated H I line spectrum is about ~90 km s^{-1}. The line profile is roughly symmetrical around the systemic velocity. The west side of the elongated H I structure (see Fig. 2) is redshifted while the east side is blueshifted relative to the average velocity. The southern H I cloud is also blueshifted. However, it is not clear in which plane the H I rotates. The apparent elongation of the main H I structure and its associated kinematics supports the interpretation that the H I structure forms a polar ring with a rotation axis roughly aligned with the optical major axis of the galaxy, at a

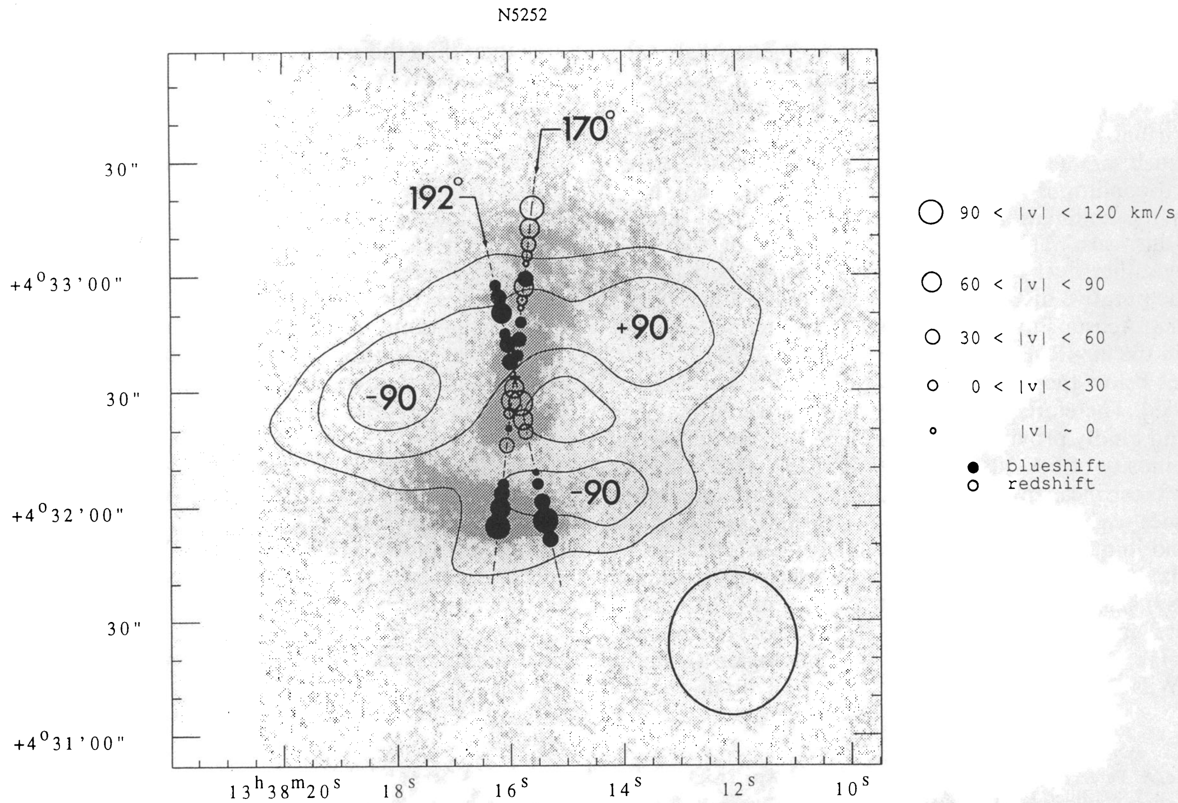

FIG. 2.—[O III] 5007 Å and H I gas kinematics. The figure is the same as Fig. 1*b* but, for sake of clarity, only three H I contours are plotted and the level of darkness of the [O III] image has been reduced. [O III] velocities relative to the nucleus by Held et al. (1992) are represented by circles. They are distributed along the two slit positions measured by the authors. The maximum amplitude of the H I velocity, relative to the nucleus, at each of the main H I regions is directly indicated on the figure.

position angle of 15°. The plane through the ring is neither aligned with the optical continuum image nor with the image of the ionized gas, and thus defines a new plane of symmetry in the system. The optical disk and the ionized gas define the two other planes of symmetry of NGC 5252.

An alternative interpretation is that all the gas, the shells of ionized gas and the two regions of the neutral gas, form a single disk. This hypothesis is supported by the fact that the kinematics of the extended ionized gas, although distorted in detail, shows a general rotation pattern similar to that seen in H I, with a maximum amplitude of ~ 100 km s^{-1}. The biggest circles in Figure 2 correspond to velocities of 90 km s^{-1} or larger, these are found in the outer parts of the ionized gas and also at the central regions at about 3 kpc radius. Interestingly, both the southern H I cloud and the southern ionized arc have a negative redshift, whereas the west side of the outermost northern shell of ionized gas has a positive redshift like the west side of the neutral gas (see Fig. 2). This rough agreement in sense and maximum amplitude of the velocities suggests a physical link between the neutral and ionized gas. In such a picture, the neutral gas does not define a new plane of symmetry and therefore only two independent systems exist, namely the stellar body of the galaxy and the gaseous disk. As indicated by TT, the series of shells seen in the ionized gas could represent illuminated sectors of ring structures around the galaxy.

2.3. *Environment of NGC 5252*

Finally, we would like to draw attention to the possible origin of the gas in NGC 5252. One plausible explanation for the presence of H I in early type galaxies is that the gas has been acquired by interaction with gas-rich companion galaxies (van Woerden et al. 1983; van Gorkom et al. 1986). All three cataloged galaxies within the primary beam of our VLA observations (UGC 8636, CGCG 045.060 and CGCG 045.062) turned out to be H I rich and at a redshift within 200 km s^{-1} of that of NGC 5252. The total amount of H I measured in these galaxies ranges from a factor of 1 to a factor of 5 of the value observed for NGC 5252. Optical identification and a kinematic study of these galaxies will be discussed elsewhere (Freudling & Prieto 1993).

3. CONCLUSIONS

To summarize, the main point of this paper is the following. Radio and optical observations of NGC 5252 reveal a sectorized distribution of neutral and ionized gas in this galaxy. The fact that both physical states can exist at a similar distance from the nucleus reveals the intrinsic anisotropy of the radiation field. This conclusion holds independent of the possible physical connection between the ionized and neutral gas and of the morphology of H I. The key point is that there is neutral gas at radii from the nucleus where it could be reached by the ionizing radiation if it were isotropic. Only a spatial location of the H I much farther away from the nucleus of NGC 5252 than its projected position would invalidate this argument. However, the redshift coincidence between neutral and ionized gas, the velocity amplitude of the neutral gas and the suggestive interconnection between the H I and [O III]—kinematical and spatial—leads us to consider this possibility as extremely unlikely.

N5252 is unique because of the availability of maps for both the ionized gas and the neutral gas. The former reveals the volume around the nucleus which contains ionizing radiation, the latter shows positions where no ionizing radiation can be present. Virtually a complete sphere centered around the nucleus is such sampled by gas and makes it possible to derive the physical conditions within that volume. Therefore, information on the collimation mechanism is particularly interesting in this case. The expected reprocessing of the UV photons by either dust clouds (Genzel, Cameron, & Krabbe 1993) or the putative disk or torus (Antonucci & Miller 1985; Madau 1988; Acosta-Pulido et al. 1990) is expected to leave its signature in the far-IR. Because of its distance, NGC 5252 has *IRAS* fluxes below the limiting flux of the *IRAS* Faint Source Survey (1989). Therefore, *IRAS* addscan fluxes were obtained at IPAC and kindly provided to us by N. Y. Lu. We derived a far-IR luminosity of $6 \times 10^9\ L_\odot$ for NGC 5252. This value is lower than those measured in Seyfert 2 galaxies with later type morphologies, e.g., NGC 1068, but well within the range of values found in other S0 Seyfert galaxies of either type 1 or 2, such as galaxies in the subsample of S0/a Seyferts in Heckman et al.'s (1989) sample. In particular, Mrk 573 and NGC 2110, two Seyfert 2 galaxies which like NGC 5252 are of type S0 and show bipolar extended ionized gas morphologies (Haniff, Ward, & Wilson 1992) have very similar far-IR luminosities, about 6 and $8 \times 10^9\ L_\odot$, respectively. Such far-IR luminosities are larger than those measured in normal galaxies. Heckman et al. found an average far-IR luminosity of $3.3 \times 10^9\ L_\odot$ for their sample of normal galaxies which includes morphological types from S0 to Sbc. This IR excess in these S0 Seyfert 2 galaxies is presumably not related with any stellar activity but directly linked to the presence of high dust or molecular gas contents in the surroundings of the nucleus. The presence of a large mass of H I outside of the plane of the galaxy in NGC 5252 is probably the result of tidal interaction with one of its companion galaxies. In such a scenario, molecular material collapses toward the center where it may form the torus that obscures the nuclear radiation. Future CO observations will provide more information concerning the presence of such obscuring material in the surroundings of the nucleus of NGC 5252.

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REFERENCES

Acosta-Pulido, A., Perez, I., Calvani, M., & Wilson, A. 1990, ApJ, 365, 119
Antonucci, R. R. J., & Miller, J. S. 1985, ApJ, 297, 621
Browne, I. W. A., & Jackson, N. 1991, in Physics of Active Galactic Nuclei, ed. W. J. Duschl & S. J. Warner (Berlin: Springer), 618
Freudling, W., & Prieto, M. A. 1993, in preparation
Genzel, R., Cameron, M., & Krabbe, A. 1993, in The Nearest Active Galaxies, ed. J. Beckman & L. Colina, in press
Haniff, C. A., Ward, M., & Wilson, A. 1992, ApJ, 368, 167
Heckman, T. M., Blitz, L., Wilson, A. S., Armis, L., & Miley, G. K. 1989, ApJ, 342, 735
Held, E. V., Capaccioli, M., & Cappellaro, E. 1992, in AIP Conf. Proc. No. 254, Testing the AGN Paradigm, ed. S. S. Holt, S. G. Neff, & C. M. Urry (New York: AIP), 613
Kinney, A. L., Antonucci, R. R. J., Ward, M., Wilson, A. S., & Whittle, M. 1991, ApJ, 377, 100
Madau, P. 1988, ApJ, 327, 116
Moshir, M., et al. 1989, Explanatory Supplement to the *IRAS* Faint Source Survey (Pasadena: JPL)
Pogge, R. W. 1989, ApJ, 345, 730
Prieur, J. L. 1990, in Dynamical and Interaction of Galaxies, ed. R. Wielen (Berlin: Springer), 72
Tadhunter, C., & Tsvetanov, Z. 1989, Nature, 341, 422 (TT)
Unger, S. W., Pedlar, A., Axon, D. J., Whittle, M., Meurs, E. J. A., & Ward, M. 1987, MNRAS, 228, 671
van Gorkom, J. H., Knapp, G., Raimond, E., Faber, S., & Gallagher, J. 1986, AJ, 91, 791
van Woerden, H., van Driel, W. & Schwarz, U. 1983, in IAU Symp. 100, Internal Kinematic and Dynamics of Galaxies, ed. E. Athanassoula (Dordrecht: Kluwer), 99
Wilson, A., Ward, M., & Haniff, C. 1988, ApJ, 334, 121