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A search for extragalactic H_2O maser emission towards IRAS galaxies

Detection of a maser from an infrared-luminous merger, NGC 6240

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Abstract. We report the result of an on-going survey for 22 GHz H_2O maser emission towards infrared luminous galaxies. The observed galaxies were selected primarily from the IRAS bright galaxy sample. The survey has resulted in the detection of one new maser. The new maser was discovered towards the [U]LIRG/merger galaxy NGC 6240, which contains a LINER nucleus. This is the first detection of an H_2O maser towards this class of galaxy, they are traditionally associated with OH megamaser sources. The detected maser emission is highly redshifted ($\sim$260–300 km s^{-1}) with respect to the adopted systemic velocity of the galaxy, and we identified no other significant emission at velocities $\lesssim \pm 500$ km s^{-1} relative to the systemic velocity. The presence of high-velocity maser emission implies the possible existence of a rotating maser disk formed in the merging process. The large maser luminosity ($\sim$40 $L_\odot$) suggests that an active galactic nucleus could be the energy source that gives rise to the water emission. Alternatively, the maser emission could be associated with the previously observed double radio source in the centre of the galaxy. Interferometric observations with high angular resolution will be able to clarify the origin of the new maser.

Key words. masers – galaxies: active – galaxies: individual (NGC 6240): radio lines – ISM: molecules

1. Introduction

The discovery of the highly Doppler-shifted maser emission at 22 GHz in the 6_{16}–5_{23} transition of H_2O in NGC 4258 (Nakai et al. 1993), has resulted in a resurgence of single-dish surveys for extragalactic water masers. Recent maser surveys towards active galactic nuclei (AGN) have been motivated by the VLBI observations of a sub-parsec-scale H_2O maser disk rotating around a central massive object in NGC 4258 (Miyoshi et al. 1995). The detection and imaging of such H_2O *megamaser* emission enables us to probe the kinematics and dynamical structures of parsec-scale circumnuclear disks (Moran et al. 1999). H_2O megamasers studied to date can be categorised into two types; *disk masers* residing in a (sub-)parsec scale disk around an active nucleus, and *non–disk masers* which are seen significant distances from the nucleus. The latter can also be sub-categorised into two types: jet masers associated with radio jets e.g. NGC 1068 (Gallimore et al. 1996), NGC 1052 (Claussen et al. 1998), and Mkn 348 (Falcke et al. 2000; Peck et al. 2001; Xanthopoulos & Richards 2001) or a nuclear

outflowing component such as that observed in the Circinus galaxy (Greenhill 2000). Masers associated with jets appear to have different spectral characteristics than the *disk masers*, the spectra tend to be broad (a few hundred km s^{-1}) and featureless, whereas the *disk masers* tend to consist of bright, narrow components clustered in velocity groups. H_2O megamasers generally seem to trace the nuclear activity in the central parsecs of AGN. To deduce the general properties of such megamasers and those of the central parsecs of AGN, we need to increase the number of detections of water megamasers.

At this time, 24 extragalactic water masers inside AGN have been discovered with single-dish surveys (e.g. Moran et al. 1999). The detection rates of new masers remain quite low, less than $\sim$7% (e.g., Braatz et al. 1996; Braatz et al. 1997; Greenhill et al. 1997). From the presently known sample of sources we have already deduced some properties of H_2O megamasers. They prefer to lie in type 2 Seyfert AGN, suggesting that obscuring gas around an active nucleus coupled with long gain paths along an edge-on disk in the line of sight, plays a vital role in giving rise to strong maser emission. A number of H_2O megamasers are known to contain a parsec-scale radio "core-jet" structure which the maser can amplify in the gaseous environment.

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Table 1. Observed galaxies.

Source	α^a (1950)	δ^a (1950)	$V_{\mathrm{sys}}{}^{a,b}$ (km s^{-1})	ΔV^c (km s^{-1})	rms (mJy)	Epoch
UGC 05101	09 32 05	+61 34 37	11 809	11 580–12 070	12	A
NGC 3310	10 35 40	+53 45 49	993	500–1520	21	A
ARP 299	11 25 38	+58 51 14	3111	2880–3370	18	C
NGC 3822^f	11 39 36	+10 33 19	6120	5340–6610	16	A
NGC 4388	12 23 15	+12 56 20	2524	2290–2780	28	B
NGC 4438	12 25 14	+13 17 07	71	−160–340	32	B
NGC 4490	12 28 10	+41 55 08	565	330–820	14	A
NGC 4532	12 31 47	+06 44 39	2012	1780–2270	25	B
NGC 4631	12 39 42	+32 48 52	606	380–860	12	A
NGC 6052	16 03 01	+20 40 37	4716	4490–4990	14	A
NGC 6090	16 10 24	+52 35 04	8785	8560–9040	25	B
NGC 6240	16 50 28	+02 28 58	7339	6850–7870	4.5–7.0	B, C, D
NGC 6285	16 57 37	+59 01 47	5580	5190–6220	14	A
NGC 7674	23 25 24	+08 30 13	8671	8210–9230	28	A
UGC 12914	23 59 08	+23 12 58	4371	3890–4910	14	A

[a] From NED database.
[b] Heliocentric velocity.
[c] Observed velocity range.
[d] Observing epoch; A(23–24 April), B(9–10 May), C(13–14 June), and D(16–17 July) all in 2001.
[e] Condon et al. (1990).
[f] The source was not selected from IRAS galaxies.

Accordingly it is reasonable to search for H_2O megamasers towards type 2 Seyfert/LINER nuclei enshrouded by circumnuclear gas around a compact continuum nucleus.

Here we report the result of an on-going single-dish survey for H_2O megamasers towards AGN in infrared (IR)-luminous galaxies, and the discovery of the new maser in the galaxy NGC 6240.

2. Sample selection

The observed galaxies were primarily selected from far-infrared (FIR) luminous galaxies (IRAS galaxies) with an apparent FIR luminosity (L_{FIR}) > 10^{11} $L_\odot$ (Soifer et al. 1989). Condon et al. (1990) carried out 1.49 GHz imaging with the VLA at arcsecond resolution for these objects. Due to the now well-known correlation of L_{FIR} with radio continuum flux density for the IR-luminous galaxies, Condon et al.'s work has resulted in a significant number of detections of radio continuum sources towards such galaxies. The sample was selected from galaxies in which the ratio of 1.49 GHz continuum flux density to far-infrared (FIR) flux density ($F_{21\,\mathrm{cm}}/F_{\mathrm{FIR}}$) was >0.003, where $F_{\mathrm{FIR}} = F_{60\,\mu\mathrm{m}} + F_{100\,\mu\mathrm{m}}$. About 25 IR-luminous galaxies were selected in this way, of which 14 sources have been observed to date. Here we present the initial results of the survey. The sample observed so far is listed in Table 1.

3. Observations

The observations of H_2O emission (rest frequency: 22.23508 GHz) were made with the MPIfR 100 m radio telescope at Effelsberg between April and July 2001, as part of an extragalactic H_2O maser survey towards infrared-luminous galaxies. 15 galaxies have been observed to date (Table 1). We used a K-band HEMT receiver with two orthogonal linear polarizations. The system temperature was typically 70–110 K, depending on atmospheric conditions. The amplitude calibration was based on a flux density at 22 GHz for 3C 286 (Ott et al. 1994), and flux densities were estimated from the measured antennas temperature, $T_A{}^*$. The observations were made in position-switching mode. Typical observing time for each source was about 50–80 min, yielding rms sensitivities of ∼15–30 mJy. Pointing calibrations using nearby calibrator sources were carried out during the observations every ∼1–1.5 hours. The resultant pointing accuracy was <8″ i.e. within 20% of the antenna beam size (40″ [$FWHM$]). Uncertainties in the amplitude calibration are nominally 10–20%. The back-end digital autocorrelation system provided 4 autocorrelators for each of the 2 polarisation signals. Each autocorrelator produced a spectrum in a 40 MHz band (corresponding to a rest-frame velocity range of 540 km s^{-1}) with 512 spectral channels providing a frequency resolution of 78 kHz or 1.1 km s^{-1}. The center frequencies of the four autocorrelators were

arranged to have 10 or 20 MHz overlap (depending on source), resulting in a total velocity coverage of ± 500 km s^{-1} relative to the galaxy's systemic velocity. After adding the two polarizations together, first or second order baselines were fitted to, and subtracted from, each of the spectra.

4. The survey results

The survey of 15 sources resulted in the detection of one new H_2O megamaser. On 9 May 2001, we detected H_2O emission towards the LINER galaxy NGC 6240 (Fig. 1a), the detection was confirmed on 14 Jun. 2001 (Fig. 1b). We searched for water masers in the other 14 AGN but obtained no detections at a $3\,\sigma$ level of $\sim$40–90 mJy (Table 1). The detection of one new maser among the 15 AGN in the biased sample yields a detection rate of $\sim$6.7%, which is comparable to those of $\sim$7.0% in Braatz et al. (1997) and $\sim$3.4% in Greenhill et al. (1997). The H_2O maser in the Seyfert 2 galaxy NGC 5793 was originally selected from this sample, its discovery stimulated us to continue the programme (Hagiwara et al. 1997; Hagiwara et al. 2001). Our survey of IRAS galaxies is still ongoing, however, if we include the previous detection of the maser in NGC 5793, the detection rate in our survey is significantly higher than those mentioned above. Although the survey is incomplete, its success seems to partially depend on the assumption that the masing can be enhanced by "warm" dust emission heated by a nuclear radio source.

5. H_2O maser in NGC 6240

Figure 1 shows spectra of the H_2O maser towards NGC 6240 taken with the 100 m telescope at Effelsberg. The spectra show a prominent H_2O maser feature with a narrow velocity-width (4.3 km s^{-1} [$FWHM$]) centered at V_{LSR} = 7565 km s^{-1}. The feature is redshifted by 261 km s^{-1} from the systemic velocity (V_{sys} = 7304 km s^{-1} with respect to the local standard of rest (LSR), based on HI observations; de Vaucouleurs et al. 1991). NGC 6240 exhibits bright emission with a peak flux density of $\sim$40 mJy (Gaussian-fitted intensity is 36 mJy). Figure 2 shows a spectrum averaged over the two earlier observing epochs in Fig. 1 from which we estimate the apparent isotropic luminosity of the prominent feature alone to be $\sim$36 $L_\odot$ at a distance of 97 Mpc. In addition, we detect faint narrower (1.1 km s^{-1} [$FWHM$]) emission at V_{LSR} = 7609 km s^{-1} ($3\,\sigma$ level detection). Including both emission features, the total luminosity of the maser is $\sim$40 $L_\odot$. Prior to our observations no H_2O emission had been firmly detected (e.g. Claussen & Lo 1986), although tentative detections had been reported (Henkel et al. 1984; Braatz et al. 1994). The maser therefore appeared to be in a flaring state during our observing epochs in 2001. The peak flux density remained the same within the uncertainties of amplitude calibrations, at both early observing epochs. However, a third spectrum, taken on
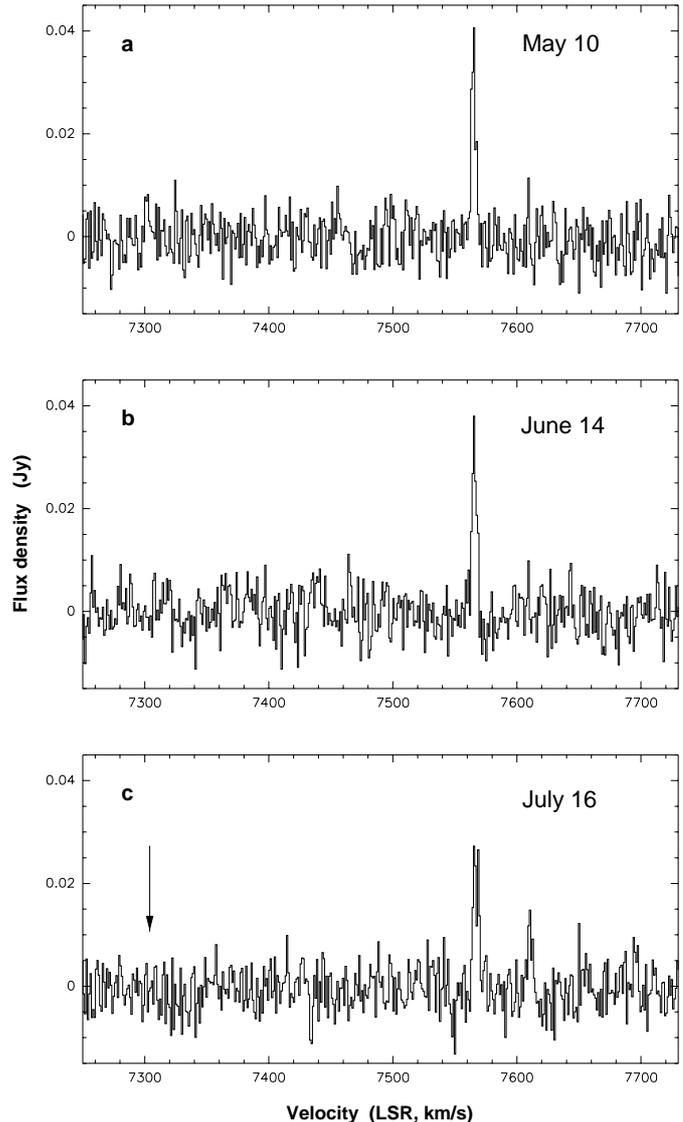

Fig. 1. Spectra of water maser emission towards NGC 6240 for different three epochs in 2001. The spectral channel spacing is 1.1 km s^{-1}. V_{sys} is denoted by an arrow. Note that the flux density of the feature at V_{LSR} = 7565 km s^{-1} clearly decreased at the last epoch **c**).

12 July 2001 shows the strongest feature declining in flux to $\sim$27 mJy while the feature at 7609 km s^{-1} is more prominent (Fig. 1c).

NGC 6240 is categorized as an (ultra) luminous infrared galaxy ([U]LIRG) with a complex structure (Sanders et al. 1988) and is one of the most distant megamasers ever detected, rivaling the "Giga Maser" in TXFS 2226–184, which lies at a distance of 100 Mpc (Koekemoer et al. 1995). The basic characteristics of the galaxy are listed in Table 2. The large IR luminosity ($>10^{10.8}$ $L_\odot$) is considered as having its origin in re-emission from a dust shell surrounding a hot core, suggesting the presence of an on-going starburst triggered by the merger of two galaxies (Sanders et al. 1988). However, recent hard X-ray measurements detected a strong iron-K emission line at $\sim$6.4 keV with an excess atomic
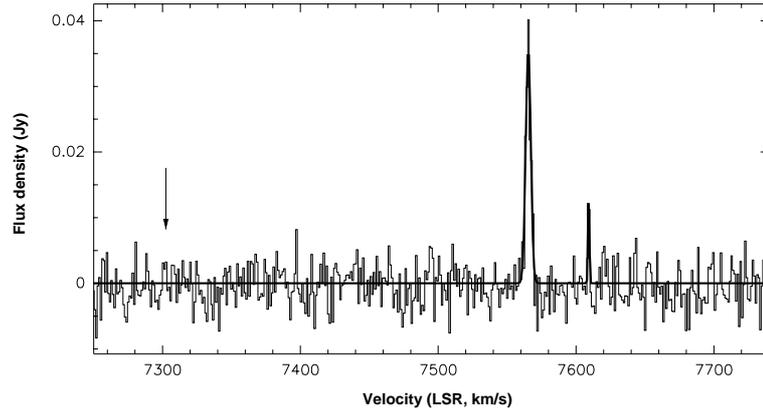
Fig. 2. Spectrum averaged over two observing epochs on 9 May and 14 June 2001. A downward arrow indicates the adopted systemic velocity of the galaxy, $V_{\mathrm{LSR}} = 7304$ km s^{-1}. Solid line indicates the result of 2-D Gaussian-fitting, assuming two Gaussian components in the observed velocity range. The fitted center velocities of each component are $V_{\mathrm{LSR}} = 7565$ km s^{-1} ($FWHM = 4.3$ km s^{-1}) and 7609 km s^{-1} ($FWHM = 1.1$ km s^{-1}) with peak flux densities of 35 mJy and 15 mJy, respectively.

Table 2. NGC 6240.

Distance[a]	97 Mpc
Systemic Velocity (21 cm HI)[b,c]	7304 ± 9 km s^{-1}
(optical)[b,c]	7192 ± 44 km s^{-1}
Inclination (optical) [d]	60°
Optical class[e]	LINER
F_ν (20 cm)[f]	386 ± 19 mJy
F_ν (100 μm)[g]	27.8 ± 1.1 Jy
F_ν (60 μm)[g]	22.7 ± 0.9 Jy
F_ν (25 μm)[g]	3.4 ± 0.1 Jy
L_{IR} (8–1000 μm)[h]	6.6×10^{11} $L_\odot$
$L_{\mathrm{X-ray}}$ (2–10 keV)[i]	4×10^{43}–6×10^{44} erg s^{-1}

[a] Assuming $H_0 = 75$ km s^{-1} Mpc^{-1}.
[b] Converted to LSR from helio centric velocity.
[c] de Vaucouleurs et al. (1991).
[d] Braatz et al. (1997).
[e] Heckman et al. (1987).
[f] VLA in B configuration (Colbert et al. 1994).
[g] Primary from NED.
[h] Sanders et al. (1988).
[i] Ikebe et al. (2000).

hydrogen column density of $\sim 10^{22}$ cm^{-2} towards the nucleus, a phenomenon which appears to be common in the presence of an AGN (Iwasawa & Comastri 1998; Vignati et al. 1999; Ikebe et al. 2000). A 5 GHz high-resolution MERLIN continuum map (Beswick et al. 2001) revealed a double source with a separation of $\sim 1.5''$ (~ 700 pc). Beswick et al concluded that the radio continuum flux found in the galaxy is a combination of a starburst and a weak AGN induced by a merger event. A molecular gas concentration, which lies between the radio sources, was imaged in CO emission on 100 parsec-scales (Bryant & Scoville 1999; Tacconi et al. 1999; Tecza et al. 2000). According to Tacconi et al. (1999), the CO emission is settling down into the two nuclei (which correspond to the

double peaks in the MERLIN map) and will likely form a central thin disk in the final stage of evolution.

6. What is the maser in NGC 6240?

The detection of H₂O masers from NGC 6240, which is exhibiting starburst activity, raises questions concerning the nuclear activity of the galaxy. The major energy source is considered to be a nuclear starburst (e.g., Tecza et al. 2000) since the ratio of the hard X-ray luminosity to the IR luminosity is small, ~ 0.01–0.1 (Table 2). Such a ratio suggests that the hard X-ray source (i.e. the AGN) is not dominant (e.g., Ikebe et al. 2000). What is the energy source that gives rise to the water maser in NGC 6240?

H₂O megamasers are often associated with a compact continuum source such as a radio core or jet. In the nuclear region of NGC 6240 the two radio sources at 5, 8.4 and 15 GHz remain unresolved at ~ 0.1 arcsec resolution. Each source has a brightness temperature upper limit (T_{b}) of $\sim 10^4$–10^5 (K) (Colbert et al. 1994; Beswick et al. 2001). (There has been no reported detection of milliarcsecond-scale structure in the galaxy.)

Tacconi et al. (1999) imaged the CO(2–1) emission peak between the two radio sources with $0.7''$ resolution, the spectral profiles show wide line-widths spanning ± 500 km s^{-1} with respect to the systemic velocity of 7339 km s^{-1}. A similar result was obtained in HCN(1–0) emission, which is a more appropriate tracer of the warm dense molecular gas that can produce 22 GHz H₂O maser emission. Both CO and HCN cover the velocities of the maser but there are no distinct velocity peaks corresponding to those of the maser, weakening the case for an association between the CO/HCN gas and the masing cloud.

The location of the H₂O maser of NGC 6240 is of great interest. MERLIN high-resolution HI absorption observations show that there exist velocity gradients against the two unresolved radio sources. The HI gas in front of the two sources differ in their velocity centroids by ~ 150 km s^{-1}; the gradients

range from $V_{LSR} = 7100$–7200 km s^{-1} and 7250–7350 km s^{-1} respectively (Beswick et al. 2001). However, there is no significant detection of HI gas at the H$_2$O maser velocities of $V_{LSR} = 7565$ and 7609 km s^{-1}, implying the masers are not associated with the observed HI absorbing gas. It is thus unlikely that the maser emission is associated with these two radio sources, which are widely accepted as being supernova remnants. This is consistent with the fact that total maser luminosity, which we estimate to be $\sim$40 $L_\odot$ is an order of magnitude larger than those of extragalactic H$_2$O masers outside AGN (0.1–1.0 $L_\odot$), i.e. *kilomasers* that are associated with star forming regions in nearby galaxies (Claussen et al. 1984; Ho et al. 1987; Greenhill et al. 1990). Consequently, it is likely that the maser in NGC 6240 is directly associated with nuclear activity, the presence of which was probed by the hard X-ray measurements.

Given the detection of the features redshifted by 260–300 km s^{-1} from V_{sys} and the narrowness of each line, it is reasonable to assume that the maser might originate from a well-defined region where the masing gas is receding relative to the molecular gas disk observed on 100 pc-scales. One can also speculate on the possible existence of an edge-on molecular gas disk rotating around a super massive object by analogy with other megamasers (Moran et al. 1999). Such a hypothesis is supported by the nature of the observed spectrum of the H$_2$O maser towards NGC 6240 and its similarity to that of the so-called *disk masers*. If such a scenario was true, the H$_2$O maser should lie in the dynamical center of the galaxy, where the observed dense molecular gas will eventually settle down between the two radio sources and form a disk.

NGC 6240 has often been compared with the prototype ULIRG Arp 220 (IC 4553) from which hard X-ray radiation or other evidence of AGN activity has never been incontrovertibly detected (Kii et al. 1997; Genzel et al. 1998; Smith et al. 1998 and references therein). The galaxy is a merging system showing a large concentration of dense molecular gas between twin stellar/starburst nuclei (Scoville et al. 1997). H$_2$O maser emission has not been detected in Arp 220 (Braatz et al. 1997) however, it is the prototype of the class of galaxies that exhibit OH megamaser emission. Recent surveys with Arecibo have revealed many new OH megamaser sources bringing the total number of detections to almost 100 (Darling & Giovanelli 2001). Most of the OH megamaser detections are in galaxies that are classified as [U]LIRGs, and all [U]LIRGs appear to be merging systems. The most remarkable thing is that H$_2$O nuclear megamasers and OH megamasers are mutually exclusive: No galaxy observed to date contains both an OH megamaser and a nuclear H$_2$O megamaser. NGC 6240 does not show OH emission, however OH gas is seen in intense absorption (e.g. Baan et al. 1998). This is similar to the case of the OH absorption towards the nucleus of the megamaser NGC 5793 (Hagiwara et al. 2000). Until now there have been no detections of H$_2$O masers towards merging systems, NGC 6240 appears to break the mould.

The presence of strong H$_2$O maser emission and the iron-K line in NGC 6240 might mean that the galaxy is experiencing a different phase of merging from that of Arp 220 i.e. compact single disk formation surrounding a "central engine", thereby placing it the final evolution stage in galaxy-galaxy merging.

7. Conclusions

We have made the first detection of H$_2$O megamaser emission from a [U]LIRG/merger galaxy. We have detected emission in the LINER galaxy NGC 6240, the maser features are observed to be by 260–300 km s^{-1} redshifted with respect to the systemic velocity and to have a luminosity of ($\sim$40 $L_\odot$). The maser could arise from a dense circumnuclear molecular cloud on a $\sim$100 parsec scale or from a spatially compact maser disk inferred from the presence of the high velocity maser feature(s). The interpretation of the observed maser is not unique, though we favour the latter case. Interferometric observations of the new maser will provide an opportunity to investigate the kinematics of the ongoing merger.

References

Baan, W. A., Salzer, J. J., & LeWinter, R. D. 1998, ApJ, 509, 633

Beswick, R. J., Pedlar, A., Mundell, C. G., et al. 2001, MNRAS, 325, 151

Braatz, J. A., Wilson, A. S., & Henkel, C. 1994, ApJ, 437, L99

Braatz, J. A., Wilson, A. S., & Henkel, C. 1996, ApJS, 106, 51

Braatz, J. A., Wilson, A. S., & Henkel, C. 1997, ApJS, 110, 321

Bryant, P. M., & Scoville, N. Z. 1999, AJ, 117, 2632

Claussen, M. J., Heiligman, G. M., & Lo, K. Y. 1984, Nature, 310, 298

Claussen, M. J., & Lo, K.-Y. 1986, ApJ, 308, 592

Claussen, M. J., Diamond, P. J., Braatz, J. A., et al. 1998, ApJ, 500, L129

de Vaucouleurs, G., de Vaucouleurs, A., Corwin, H. G., et al. 1991, The Third Reference Catalogue of Bright Galaxies (Berlin: Springer)

Colbert, E. J. M., Wilson, A. S., & Bland-Hawthorn, J. 1994, ApJ, 436, 89

Condon, J. J., Helou, G., Sanders, D. B., et al. 1990, ApJS, 73, 359

Darling, J., & Giovanelli, R. 2001, AJ, 121, 1278

Falcke, H., Henkel Chr., Peck, A. B., et al. 2000, A&A, 358, L17

Gallimore, J. F., Baum, S. A., O'Dea, C. P., et al. 1996, ApJ, 462, 740

Genzel, R., Lutz, D., Sturm, E., et al. 1998, ApJ, 498, 579

Greenhill, L. J., Moran, J. M., Reid, M. J., et al. 1990, ApJ, 364, 513

Greenhill, L. J., Herrnstein, J. R., Moran, J. M., et al. 1997, ApJ, 486, L15

Greenhill, L. J. 2000, Proceedings of the 5th EVN Symp., ed. J. E. Conway, A. G. Polatidis, R. S. Booth, et al. (Gothenburg, Sweden), 101

Hagiwara, Y., Kohno, K., Kawabe, R., et al. 1997, PASJ, 49, 171

Hagiwara, Y., Diamond, P. J., Nakai, N., et al. 2000, A&A, 360, 49

Hagiwara, Y., Diamond, P. J., Nakai, N., et al. 2001, ApJ, 560, 119

Heckman, T. M., Armus, L., & Miley, G. K. 1987, AJ, 93, 276

Henkel, C., Guesten, R., Wilson, T. L., et al. 1984, A&A, 141, L1

Ho, P. T. P., Martin, R. N., Henkel, C., et al. 1987, ApJ, 320, 663

Ikebe, Y., Leighly, K., Tanaka, Y., et al. 2000, MNRAS, 316, 433

Iwasawa, K., & Comastri, A. 1998, MNRAS, 297, 1219

Kii, T., Nakagawa, T., Fujimoto, R., et al. 1997, Proceedings of X-Ray Imaging and Spectroscopy of Cosmic Hot Plasmas, ed. F. Makino, & K. Mitsuda (Tokyo: Universal Academy Press), 161

Koekemoer, A. M., Henkel, C., Greenhill, L. J., et al. 1995, Nature, 378, 697

Miyoshi, M., Moran, J., Herrnstein, J., et al. 1995, Nature, 373, 127

Moran, J. M., Greenhill, L. J., & Herrnstein, J. R. 1999, J. Astrophys. Astron., 20, 165

Nakai, N., Inoue, M., & Miyoshi, M. 1993, Nature, 361, 45

Ott, M., Witzel, A., Quirrenbach, A., et al. 1994, A&A, 284, 331

Peck, A., Falcke, H., Henkel Chr., et al. 2001, in preparation

Sanders, D. B., Soifer, B. T., Elias, J. H., et al. 1988, ApJ, 325, 74

Scoville, N. Z., Yun, M. S., & Bryant, P. M. 1997, ApJ, 484, 702

Smith, H. E., Lonsdale, C. J., Lonsdale, C. J., et al. 1998, ApJ, 493, L17

Soifer, B. T., Boehmer, L., Neugebauer, G., et al. 1989, AJ, 98, 766

Tacconi, L. J., Genzel, R., Tecza, M., et al. 1999, ApJ, 524, 732

Tecza, M., Genzel, R., Tacconi, L. J., et al. 2000, ApJ, 537, 178

Vignati, P., Molendi, S., Matt, G., et al. 1999, A&A, 349, L57

Xanthopoulos, E., & Richards, A. M. S. 2001, MNRAS, 326, 37