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Location of H_2O maser in the double-nuclei system of NGC 6240

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Abstract. We performed VLA observations of the 22 GHz H_2O maser emission in the merging galaxy NGC 6240, which hosts the well-known double active nuclei. In a previous paper, we reported on the first solid detection of the H_2O maser emission in 2001. After two abortive attempts due to the weakness and probable variability of the emission, the maser was detected with the VLA in June 2002. The emission is unresolved at ~0.3 arcsec and coincides with the southern 22 GHz continuum peak to ~0.007 arcsec (~3 pc: D = 97 Mpc). The detection of the maser in the southern nucleus indicates that nuclear activity of the galaxy, which is significant in X-ray and far-infrared (FIR) bands, lies mainly in the southern nucleus, and the nucleus without a high brightness peak could be explained by thick dust emitting FIR radiation. We favour the idea that the maser in NGC 6240 is associated with the AGN-activity.

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

1. Introduction

1.1. Background of extragalactic H_2O masers

A number of attempts to find more extragalactic H_2O masers (6_{16}–5_{23}) have been made in recent times, stimulated by the discovery of the highly Doppler-shifted maser emission symmetrically straddling the systemic velocity of the galaxy in NGC 4258 (Nakai et al. 1993). VLBI observations of the maser emission in NGC 4258 revealed the presence of a sub-parsec-scale H_2O maser disk rotating around a central massive object (Miyoshi et al. 1995). After the discovery of the masing torus surrounding a "black hole" in NGC 4258, very few other such sources suitable for studying the central sub-parsecs of Active Galactic Nuclei (AGN) have been discovered, but astronomers need more candidates to probe the full range of the kinematics and dynamical structures of sub-parsec-scale circumnuclear regions in AGN. This kind of study is possible through the technique of radio interferometry. The extragalactic H_2O masers observed and studied to date can be categorized into two types in terms of the origin of the emission. Most of *low-luminosity* masers (L_{H_2O} <~ 1 $L_\odot$) have been observed outside galactic nuclear regions, and are associated with star forming regions and (compact-)HII regions, suggesting that the masers have no direct connection to AGN-activity. *High-luminosity* masers (L_{H_2O} >> 10 $L_\odot$) are apt to be located in or nearby an active nucleus, or to be associated with jet-activity. Such a water maser which associates with the AGN-activity is a *nuclear maser*. In either case they trace the nuclear activity within the central few parsecs of the AGN. There are also a number of masers with luminosity on the order of 10 $L_\odot$, for instance, those in Mrk 1 and NGC 5506 (Braatz et al. 1994).

The origins of H_2O masers with luminosities in the range 10 $L_\odot$ < L_{H_2O} < 100 $L_\odot$ have not been well studied in comparison with those of higher luminosity because the H_2O emission is generally not sufficiently bright for radio interferometric observations with reasonable sensitivities. Intensity variabilities on time scales of weeks to months are commonly observed in these masers, which has posed difficulties in determining the optimum timing of interferometric experiments. Currently, about 25–30 extragalactic H_2O masers, excluding the low luminosity masers, are known. However, only about ten of them have been so far imaged at milliarcsecond resolution using VLBI (Moran et al. 1999; Greenhill 2000; Hagiwara et al. 2001a; Ishihara et al. 2001). Radio interferometric studies of this sort of H_2O maser are quite challenging, but are necessary to investigate the overall properties of the H_2O masers in active galaxies regardless of their maser intensity. The apparent luminosity of the maser is not always relevant to its intrinsic properties.

In a previous paper, we reported on the single-dish detection of the H_2O maser in NGC 6240 (Hagiwara et al. 2002a), and here present the results of follow-up observations at sub-arcsecond angular resolution aimed at investigating the spatial distribution of the maser.

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1.2. NGC 6240

NGC 6240 ($D = 97$ Mpc, assuming that H_0 is 75 km s^{-1} Mpc^{-1}; 0.1″ = 48.5 pc) is a well-studied galaxy at various wavelengths. It is a prototypical ultraluminous FIR galaxy with a complex optical structure, hosting a LINER nucleus (Heckman et al. 1987). The huge FIR luminosity ($>10^{11}$ $L_\odot$) is considered to originate from re-emission of ultraviolet radiation processed by a dust shell surrounding a hot core, suggesting ongoing star formation in the galaxy (e.g., Sanders et al. 1988). X-ray satellite observations detected 6.4 keV Fe Kα line emission in the galaxy, showing a definite presence of an AGN together with a large X-ray luminosity of $\sim 10^{43}$–10^{44} erg s^{-1} in the 2–10 keV bands (e.g., Iwasawa & Comastri 1998). At sub-arcsecond resolution a number of hard X-ray blobs were imaged by Chandra, and some of them extend several kiloparsec from the center of the galaxy (Lira et al. 2002). 5 GHz high-resolution continuum MERLIN maps made by Beswick et al. (2001) showed two compact radio sources (double nuclei) with non-flat spectral indices (∼0.7–0.8 at 4.9–15 GHz, Colbert et al. 1994; Carral et al. 1990), and they are separated by 1.″5 at the highest resolution so far attained (∼0.1 arcsec) in the nuclear region. The velocity fields of the broad HI absorption towards these components are seen running along the position angle joining the two radio nuclei. Beswick et al. (2001) found that the radio continuum flux in the galaxy is mostly dominated by a starburst component, with only a small portion arising in a low luminosity AGN. Tacconi et al. (1999) and Bryant et al. (1999) found a significant peak of CO molecular gas between the double radio nuclei. Their speculation is that the CO gas settling down between the two stellar nuclei will eventually form a central thin disk. With lower angular resolutions but higher sensitivities than MERLIN, the VLA revealed HI and OH absorption structures, which agree with those of H_2, CO, and H_α (Baan & Hofner 2002). There has been an open discussion on the need to introduce an AGN in NGC 6240 as an energy supplier sustaining the large infrared luminosity, however, no one has yet succeeded in determining the location of the predicted AGN in the double nuclei system at any wavelengths.

1.3. H_2O maser in NGC 6240

Tentative detections of an H_2O maser were made by Henkel et al. (1984) and Braatz et al. (1994), although never confirmed. Hagiwara et al. (2002a) reported on the first clear detection of the water maser in the galaxy in May 2002. They also detected intensity variability on timescales of weeks to months by means of single-dish monitoring of the two distinct components, one of which lies at $V_{\rm LSR}$ = 7565 km s^{-1} and the other at $V_{\rm LSR}$ = 7609 km s^{-1}. Given the fact that the apparent maser luminosity of the two components is about 40 $L_\odot$, well above that of the typical starforming masers, and the emission is highly redshifted by some 400 km s^{-1} with respect to the adopted systemic velocity of $V_{\rm LSR}$ = 7131 km s^{-1} (Hagiwara et al. 2002a), the maser is likely to arise from the AGN activity and can be used to probe the kinematics in the galaxy.

2. Observations and data analysis

2.1. The 100-m radio telescope in Effelsberg

After the first single-dish detection of the H_2O maser emission in the rotational 6_{16}–5_{23} transition (rest frequency = 22.23508 GHz) towards NGC 6240 in May 2001 (Hagiwara et al. 2002a), we observed the maser at several epochs until September 2002. All the observations were performed with the Max-Planck-Institut für Radio astronomie (MPIfR) 100-m radio telescope in Effelsberg using a two channel K-band HEMT receiver with dual polarizations and a digital autocorrelator (AK90) as a backend. The backend correlator provided a total bandwidth of 4×40 MHz for each polarization (velocity coverage ≃2100 km s^{-1}) with a spectral resolution of 78 kHz (1.1 km s^{-1}). The beam size of the telescope is so small (∼40″ (HPBW) at 22 GHz) that the frequent calibration of telescope pointing was critical. It was determined by observing a nearby quasar 1655+077 every 1.5–2 hrs during the observations, yielding the pointing accuracy of 4″–6″. More details of the observing parameters were remarked in Hagiwara et al. (2002a). Data analysis consisted of averaging the spectra and subtracting a linear baseline in general, but occasionally a nonlinear baseline.

2.2. Very Large Array

NRAO[1] Very Large Array (VLA) observations were carried out in the B configuration on 16 July 2002. Prior to that epoch, VLA or VLBA observations had been attempted several times in 2001 with no clear detections; a list of observations is displayed in Table 1. The current observations (this paper) employed a single IF band of 12.5 MHz divided into 64 channels of width 2.64 km s^{-1} each. The band was centered at an LSR velocity ($V_{\rm LSR}$) of 7585 km s^{-1}, which is about 450 km s^{-1} redshifted from the systemic velocity of the galaxy. After removal of several channels at the band edges, the usable velocity range was 7510–7665 km s^{-1}. To detect maser lines with weak flux densities of <50 mJy, we conducted phase-referencing observations using a nearby quasar, 16582+074 as a phase-reference source. The phase-referencing observations were executed in a sequence of 3 min scans with cycling interval of 140 s for NGC 6240 and 40 s for 16582+074. The total observing time was three hours, and the resultant synthesized beam has a $FWHM$ size of 0.″29 × 0.″26 with uniform weighting and a position angle of −34°. The amplitude and bandpass calibrations were made by observing 3C 286, assuming S(3C 286) = 2.59 Jy at 21.7 GHz. The data were calibrated and mapped in the standard way using AIPS. The continuum emission was subtracted from the spectral line visibility cube using UVLSF, and then velocity channel maps of the H_2O emission were made for each velocity channel. The resultant 64 channel maps each had a typical rms noise level of 1.3 mJy beam^{-1}. The continuum emission was imaged with an rms noise of 0.26 mJy beam^{-1}.

[1] The National Radio Astronomy Observatory (NRAO) is operated by Associated Universities, Inc., under a cooperative agreement with the National Science Foundation.

Table 1. Summary of observations.

Telescope	Date	Configuration	rms[a] (mJy beam^{-1})	Velocity range ($V_{\rm LSR}$)	Comments
Effelsberg	10 May 2001		5–7	6850–7870	Hagiwara et al. (2002a)
Effelsberg	17 Jul. 2001		5–7	6850–7870	Hagiwara et al. (2002a)
VLA	5 Aug. 2001	C	~5	7545–7625	3 σ[b]
VLA	1 Oct. 2001	D	~5	7545–7625	Non-detection
VLBA	4 Oct. 2001	VLBA 10	~6	7255–7355	Non-detection
				7535–7635	Non-detection
Effelsberg	4-6 Mar. 2002		~15	6700–8000	
VLA	16 Jun. 2002	B	1.3[c]	7525–7665	This paper
Effelsberg	14 Sep. 2002		~20	5900–7750	No components were detected

[a] rms noise level per velocity channel of 1.1 km s^{-1} (Effelsberg), 1.3 km s^{-1} (VLA), and 1.7 km s^{-1} (VLBA).
[b] Detection level is insufficient for study in our research.
[c] 2.6 km s^{-1} spectral resolution.

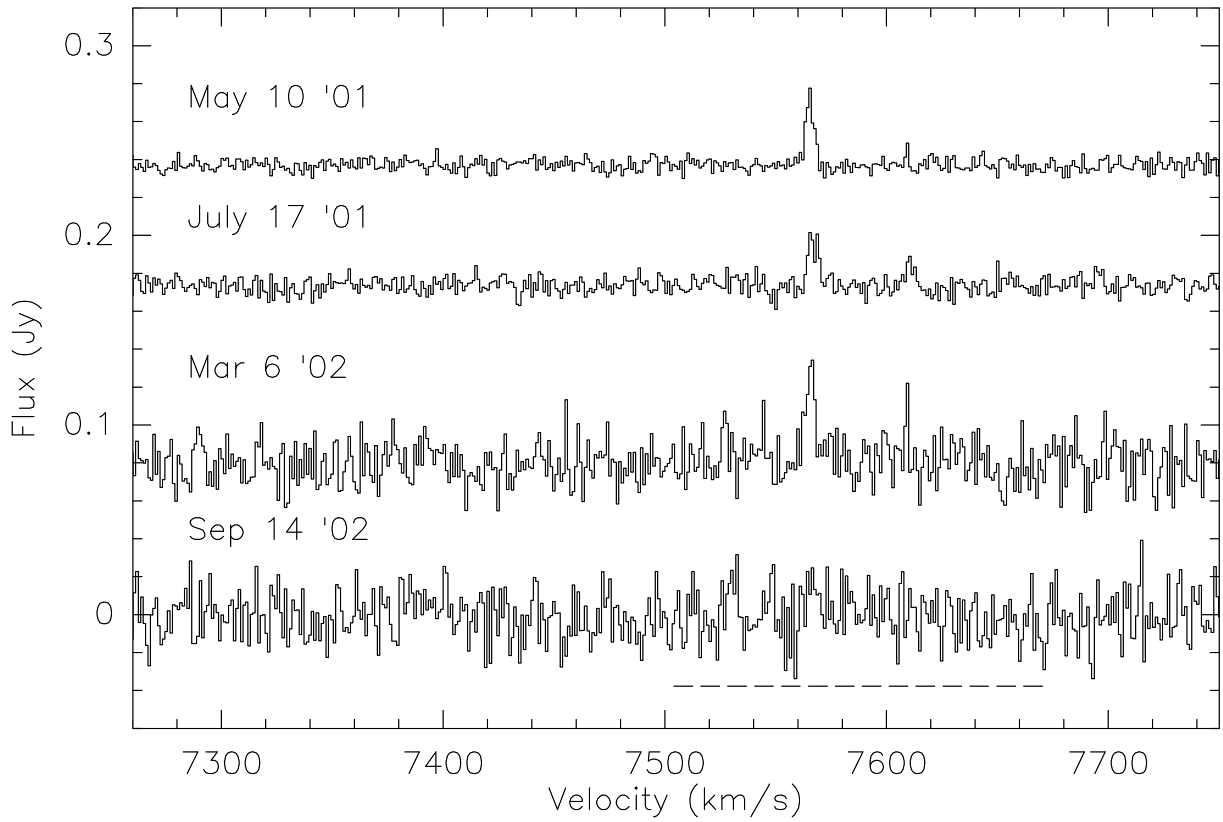

Fig. 1. Spectra of all the detected maser components for 4 epochs of the single-dish observations. The systemic velocity of the galaxy is $V_{\rm LSR}$ = 7131 km s^{-1}in the radio definition. The spectral channel resolutions are 1.1 km s^{-1}. The dotted line indicates the observed velocity range by the VLA. Two features of $V_{\rm LSR}$ = 7565 km s^{-1} and 7609 km s^{-1} were visible except at the fourth epoch. The VLA detected only the 7609 km s^{-1} feature between epochs March 6 and September 14 in 2002. The differences in the noise levels are primarily due to differences in the integration times.

3. Results

3.1. Effelsberg

Figure 1 shows H_2O maser spectra obtained from the MPIfR 100-m telescope for 4 epochs between 10 May 2001 and 14 September 2002. Each spectrum contains the two distinct redshifted components at $V_{\rm LSR}$ = 7565 km s^{-1} and 7609 km s^{-1} and other weaker components that require confirmation. We searched for maser emission primary from $V_{\rm LSR} \simeq$ 6800–7800 km s^{-1}. Occasionally, the highly blueshifted velocities ranging to $V_{\rm LSR}$ = 5900 km s^{-1} were searched (Table 1). No emission was distinctly detected except for the two components with 3σ limits of 15–60 mJy. The spectra of the two epochs in 2001 have better signal-to-noise ratios than those in 2002 largely because the integration times are much longer. Given the fact that the velocities of the two components were not changed over 8 months, an upper limit of drift rate of each line is 1.3 km s^{-1} year^{-1}. The flux

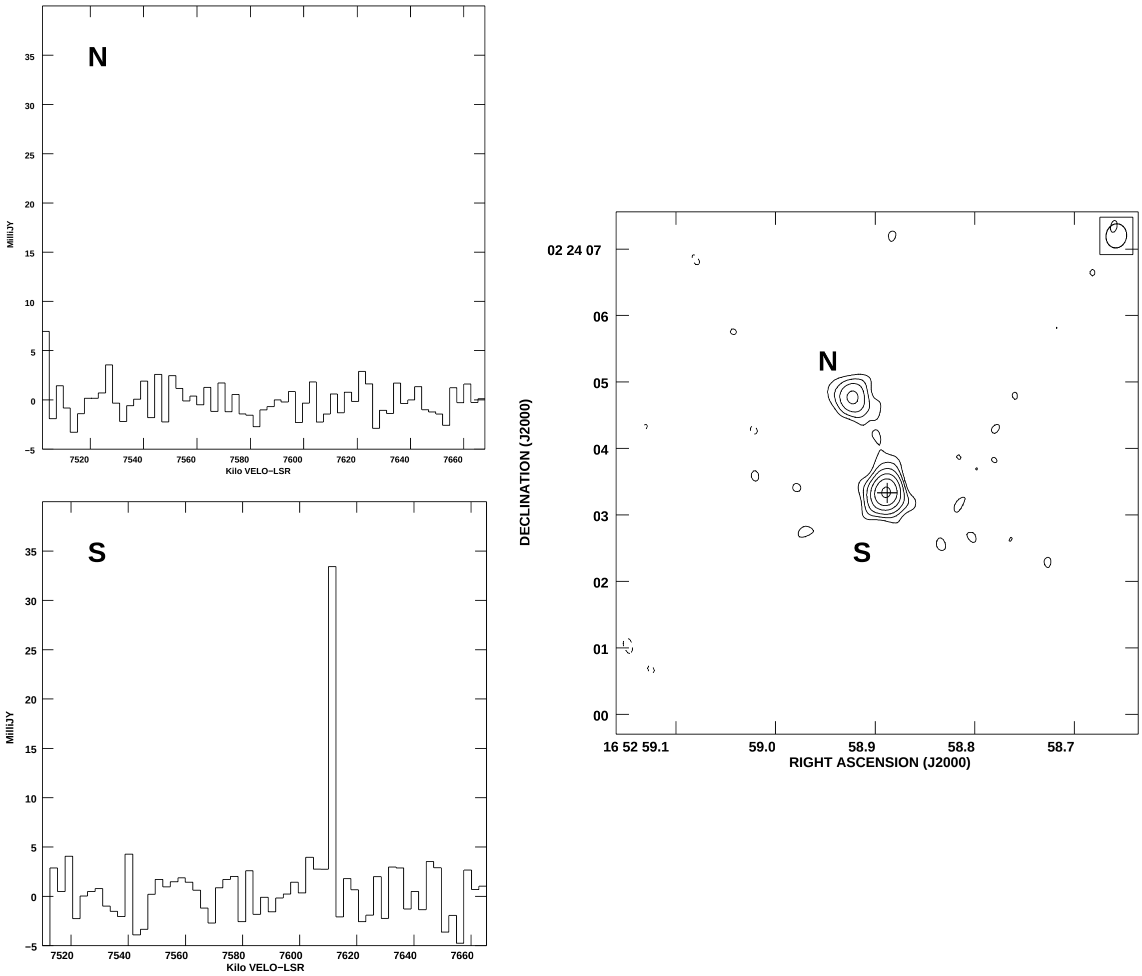

Fig. 2. 22 GHz radio continuum image of NGC 6240. The synthesized beam is plotted in the upper right corner. Two H_2O maser spectra are displayed against the double nuclei. The data were taken on 16 June 2002 by the VLA in B configuration. The velocity resolutions of the spectra are 2.64 km s^{-1}. The maser emission shows only one component centered on 7611 km s^{-1}, which is probably identical to the one at 7609 km s^{-1} in Fig. 1. Contours are −5.7, 5.7, 10, 17, 30, 51, and 90% of peak flux density of 12.3 mJy beam^{-1}. The position of the maser emission peak, marked by a cross in the image (The extent of the cross does not reflect position errors.), coincides exactly the southern continuum nucleus.

density of the $V_{\rm LSR}$ = 7565 km s^{-1} component was measured to be ~50 mJy in March 2002, the highest value recorded during our single-dish monitoring. The maser was not detected in September 2002 with an rms of ~20 mJy. Neither component was detected by the VLA snapshot made in early Oct. 2001 with a 3σ level ~15 mJy per 2.6 km s^{-1} spectral channel. This implies that the maser once faded after July 17 2001.

3.2. VLA

A naturally weighted VLA 22 GHz continuum map is shown in Fig. 2 at 0.3″ resolution; it displays double-peaked radio emission in the nuclear region in radio robes around each peak. The radio morphology is consistent with the 8.4 GHz and 15 GHz continuum images observed with the VLA in A configuration (Colbert et al. 1994). The components “S” and “N” in Fig. 2 correspond to N1 and N2 in Fig. 2 or Fig. 3 of Colbert et al. (1994). Spectra of the 22 GHz maser emission towards S and N are also shown in Fig. 2, both of which were determined from the areas containing the continuum peaks.

The maser line spectrum towards S in Fig. 2 shows a single line profile with a flux density of about 35 mJy ($L_{\rm H_2O} \simeq 20\ L_\odot$), and a centroid velocity of $V_{\rm LSR}$ = 7611 km s^{-1}, while the spectrum towards N does not show any emission within a 3σ level of ~4 mJy per velocity channel ($L_{\rm H_2O} \lesssim 2\ L_\odot$), suggesting that N houses no high luminosity maser at this time. Since the velocity resolutions of the 100-m and VLA spectra are different, there is the ambiguity in estimating the centroid velocity of each line in each spectrum. The uncertainties of velocity are not better than the VLA channel spacings of 2.64 km s^{-1}. Therefore, we conclude that the VLA component lying at $V_{\rm LSR}$ = 7611 km s^{-1} is identical to the 7609 km s^{-1} component detected by the 100-m and shown in Fig. 1. The position of the maser is $(\alpha, \delta)_{\rm J2000}$ = $16^{\rm h}52^{\rm m}58\overset{\rm s}{.}88 \pm 0\overset{\rm s}{.}05$, $+02°24'03\overset{\prime\prime}{.}3 \pm 0\overset{\prime\prime}{.}1$. The relative positional error, dominated by statistical noise, between the maser and the 22 GHz continuum peak S is estimated to be ~0.007 arcsec. Accordingly, the maser coincides with the continuum peak within an astrometric uncertainty of ~0.007 arcsec, or ~3 pc. The maser emission remains unresolved at our angular resolution of 0.26″, or 126 pc. Assuming a Gaussian distribution of the H_2O emission, the source size deconvolved by the clean beam is 0.12×0.08 arcsec (58 pc×39 pc). H_2O line emission was not detected with a 4σ limit of 5.2 mJy from any other observed points in the galaxy, including towards N. We reported earlier on the marginal interferometric detection of the V_{LSR} = 7565 km s^{-1} component obtained by the VLA (C configuration) in Aug. 2001, the position of which was significantly displaced from both S and N (Hagiwara et al. 2002b). The sensitivity of that map is, however, quite poor, and the detection level of the emission was $\sim 3\sigma$. We will not use that result in the later discussion.

Time variability of the maser intensity is that the two distinct components show changes in flux density from 10–50 mJy over weeks to months. There seems to be a weak anti-correlation of intensities between the two components.

4. Discussion

4.1. Location of the H_2O maser in NGC 6240

The most significant result from our high-resolution imaging of NGC 6240 is that the spatially unresolved maser is exactly coincident with the center of the southern nucleus (S) and there is no detectable H_2O emission from the northern nucleus (N). There is compelling evidence that luminous H_2O maser emission marks the radio continuum nucleus of the galaxy as in NGC 4258 (e.g., Miyoshi et al. 1995). The detected maser in NGC 6240 may well probe the position of one of the double-nuclei, S. Given the detection of features redshifted by <400 km s^{-1} from the systemic velocity and the narrowness of each line, the maser might originate from a well-defined region, for example, a tangential point in the receding side of a rotating disk. In addition such extremely high velocity shifts of each line have never been measured in stellar jets or outflows. Alternatively, it is possible that the redshifted maser emission is associated with the jet-activity of AGN. We cannot support the latter at this moment because there has not been detection of any spatially resolved core-jet structure in S and N at the highest resolution of 0.055 arcsec (Beswick et al. 2001). The interferometric observing results at different radio frequencies leave the possibility that these two radio sources are stellar, i.e. non-galactic, components as they were resolved by milliarcsecond VLBI observations at 1.4 GHz resulting in non-detection of ultra-compact radio sources on scales of 0.5 pc–5 pc in N and S (unpublished results; Hagiwara et al.), and neither N nor S shows the flat radio spectral indices (Table 2) that are expected for such resolved nuclei (Colbert et al. 1994). The apparent H_2O maser luminosity of 20 $L_\odot$ is nevertheless brighter by two orders of magnitude than that of starforming masers such as NGC 253 and M 82; their typical H_2O maser luminosity is $\sim$0.1 $L_\odot$ or less, and neither of them lies in a nucleus, i.e. the dynamical center of the galaxy (Ho et al. 1987; Baudry & Brouillet 1996). If S is one of the real nuclei of the galaxy, the interpretation of the maser will be straightforward – a nuclear maser with the emission physically confined within 1 pc of S. It is plausible that the other maser component will be detected towards N. The absence of compact radio emission between N and S is not consistent with the detection of the CO (1-0) between them, but a radio-quiet AGN is not ruled out. The dust shell foreground to the double peak system which is responsible for the strong far-infrared emission may hide a true nucleus in the background, or obscure these nuclei. The dusty environment itself is favorable to maser emission, and the maser could be enhanced through the thick dust lane in our line of sight, amplifying the background continuum source. It is interesting that the dust in the galaxy causes highly variable extinction with A_V = 2–8 at optical bands (Scoville et al. 2000).

4.2. Physical conditions for the luminous H_2O maser

The observation that the presence of extragalactic OH and H_2O maser emission is mutually exclusive appears to be due to the different properties of host galaxies: the OH megamaser galaxies show large FIR luminosities and gas-rich properties in the circumnuclear region but do not harbor a distinct active nucleus, while the H_2O maser galaxies on the whole contain an AGN which provides the conditions necessary for maser amplification. NGC 6240 however exhibits both OH and H_2O molecular gas towards the double nuclei system. OH molecules in the galaxy are not seen to be producing maser emission but exist as absorbing gas that is extended on kiloparsec scales, suggesting that the water masing cloud and OH absorbers do not coexist. In general, do OH megamasers coexist with H_2O megamasers under similar physical environments? We note one theoretical study by Neufeld et al. (1994) on the dense circumnuclear gas in a thin gaseous layer, illuminated by X-rays from AGN, which produces the conditions that are necessary for H_2O maser excitation. When the temperature of a molecular gas phase heated by nuclear X-ray radiation from a central engine rises sufficiently ($\sim$400–1000 K), a pair of chemical reactions of $O + H_2 = OH + H$ and $OH + H_2 = H_2O + H$ will occur (e.g., Elitzur 1992). The density of OH, hence, will be relatively smaller, and the abundance ratio of water to hydrogen will be greater than 10^{-4} as the reaction progresses. Note that the temperature required to enhance the reactions is >400 K, but under such conditions the OH molecule is less likely to emit as a maser. With such H_2O abundance, the apparent luminosity of the saturated H_2O maser can range from about 30–300 $L_\odot$ pc^{-2} over a wide range of parameters of X-ray fluxes, gas pressures, densities, gas temperatures, and effective scales of X-ray heating from the surface of a slab of material, all of which are derived from reasonable observational values. Even with the introduction of a torus model instead of the slab, the luminosity will be of similar value (Wallin & Watson 1997). Such X-ray heating models producing luminous H_2O masers will not give rise to OH masers in the warm gas.

The high-luminosity maser must be located in a smaller area than the VLA synthesized beam (e.g., Claussen & Lo 1986). The location of the unresolved maser is well defined within a radius of the beam-deconvolved size of $\sim$30 pc. If we adopt the total maser luminosity of 20 $L_\odot$, the luminosity per square parsec is $L_{H_2O} \lesssim 0.01\ L_\odot$ pc^{-2}. The relative location of the maser in NGC 6240 is measured to be within 3 parsecs of its continuum peak, yielding $L_{H_2O} \simeq 0.7\ L_\odot$ pc^{-2}. Recent milliarcsecond VLBI studies have demonstrated that

Table 2. Double-nuclei in NGC 6240.

	Northern nucleus (*N*)	Southern nucleus (*S*)
RA (J2000)[a]	$14^h52^m58\overset{s}{.}92$	$14^h52^m58\overset{s}{.}89$
Dec (J2000)[a]	$+02°24'04.8''$	$+02°24'03.3''$
Systemic velocity (21 cm HI)[b]	7260 km s^{-1}	7087 km s^{-1}
Flux density (22 GHz continuum)[c]	3.9 mJy	11 mJy
Flux density (H_2O maser)	–	35 mJy
Spectral index (4.9, 8.4, 15 GHz)[d]	0.8 ± 0.15	0.7 ± 0.15

[a] Determined by VLA-B at 22 GHz (this paper).
[b] LSR velocity, assuming the radio definition (Beswick et al. 2001).
[c] Measured in a map with uniform weighting (this paper).
[d] Colbert et al. (1994).

the distribution of H_2O megamaser emission is, in general, confined to ∼1 pc of the center of galaxies (Moran et al. 1999). With this in mind, the lower limit of the NGC 6240 maser luminosity will be comparable to 20 $L_\odot$ pc^{-2}, which agrees with the minimum value of the theoretically estimated luminosity. The H_2O maser in NGC 6240 can, therefore, be explained by the AGN-activity.

4.3. Gas kinematics in NGC 6240

If the maser is a nuclear maser, it 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 (Bryant & Scoville 1999; Tacconi et al. 1999). However, our data show that the maser lies in one of the nuclei displaced by some 100 pc from the CO emission peak lying between the twin nuclei. Is this the real dynamical center of the galaxy? It is understood that there is no well-identified active nucleus in the galaxy, and the position of the detected 6.4 keV Fe line emission is uncertain (Ikebe et al. 2000). Beswick et al. (2001) found different centroid velocities of the HI absorption towards N and S; they peaked at $V_{\rm LSR}$ = 7260 km s^{-1} and 7087 km s^{-1}, respectively. The velocity ranges of the absorption do not overlap with any of the known maser components. The radial HI velocity towards S is blueshifted by about 50 km s^{-1} from the galaxy's systemic velocity ($V_{\rm LSR}$ = 7131 km s^{-1}), while the velocity towards N is redshifted by about 130 km s^{-1} to the systemic velocity (Table 2). The nucleus S clearly shows different kinematics from N. This situation is similar to the radial velocity difference between the nuclei of 150 km s^{-1} in H_2 ν = 10 S(1) and 100 km s^{-1} in the CO (J = 2 – 1) (Tecza et al. 2000).

If the maser were to exhibit a symmetric velocity distribution, we might assume that the components we detect at $V_{\rm LSR}$ = 7565 km s^{-1} and 7611 km $s^{-1}$are red-shifted components and we might therefore search for emission around the "systemic" velocity of S ($V_{\rm LSR}$ ≈ 7080 km s^{-1}), and the blueshifted counterparts of the red-shifted emission around $V_{\rm LSR}$ = 6500 km s^{-1} and 6550 km s^{-1}. However, in the latest Effelsberg observations of the maser carried out on 14 September 2002, no new components were detected within ±800 km s^{-1} centered on the systemic velocity to an rms of ∼20 mJy. On the other hand, the velocities of CO emission (J = 1 – 0, 2 – 1) span a velocity width of ±500 km s^{-1} centered on the systemic velocity, reaching to the redshifted maser velocity. The CO emission that peaks between the twin nuclei seems to trace a circumnuclear region on larger galactic disk scales. The orientation and position of the galactic scale disks such as those imaged by HI, CO or HCN gas have little correlation in general with those of a maser disk on sub-parsec scales (e.g., Hagiwara et al. 2001b). If the two radio nuclei are highly obscured by the thick dust lane and scattered by the foreground materials in the galaxy, they will be observed as less intense due to absorption and are likely to be resolved with milliarcsecond resolution. Note that the radio spectral properties of N and S are not significantly different (Colbert et al. 1994), suggesting that both of the nuclei could house AGN.

In conclusion, we propose that one of the nuclei lies in S, and the AGN activity which is more dominant at S than any other locations in the galaxy gives rise to the maser emission. However, the starburst or composite starburst plus AGN components at the nuclei cannot be ruled out, despite the fact that such a luminous (>10 $L_\odot$) water maser has not ever been observed in starburst galaxies (e.g., Claussen & Lo 1986). It is essential to measure the locations of all visible maser components with VLBI. Our interpretation would have to be reconstructed if any of the other velocity components are found to be located outside the nuclei in future observations.

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