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High-resolution study of two extragalactic H_2O masers

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Abstract. Recently, the two new extragalactic H_2O masers were discovered during our single-dish survey for 22 GHz H_2O maser emission towards infrared luminous galaxies using the Effelsberg 100m telescope. They were observed by the VLA or VLBA to determine the distribution of the maser emission. The location of the maser emission is of interest. We report on preliminary results of these follow-up observations at higher angular resolution.

1. Extragalactic H_2O maser survey

Since 2001, we have been conducting 22 GHz H_2O maser survey at the Effelsberg 100m telescope. The extragalactic H_2O masers are known to lie in type 2 Seyfert AGN or LINER, but have never been found in type 1 Seyferts so far (e.g., Braatz et al. 1997, Greenhill et al. 2002). This fact implies that molecular materials obscuring a broad line region (BLR) coupled with long gain paths along a nearly edge-on gas disk in the line of sight play a vital role in giving rise to strong maser emission. During the survey project we have discovered water maser emission in two Seyfert galaxies, one of which is the luminous far-infrared merger galaxy NGC 6240, one of the most distant (97 Mpc) ever detected (Hagiwara, Diamond, & Miyoshi 2002). The other is a type 1 Seyfert galaxy with narrower emission lines (Osterbrock & Pogge 1985), which is the first detection from this sort of objects. It seems that the maser emission in NGC 6240, which currently has a peak flux density of ~ 20 mJy, is in a quiet state after the flaring state in early 2001. Shortly after the discovery of those masers, we requested the VLA or VLBA for following up the single dish detection. Our goal of these high-resolution observing is to pinpoint the location of the emission in relation to the radio continuum structures at lower frequencies. In addition, obtaining the pc-scale distribution of the water emission in NGC 6240 will enable it to witness a process of a single black hole formation at the site of galaxy-galaxy collision. As for the latter object, the maser lines are highly symmetrical and are straddling the systemic velocity ($V_{\rm sys}$) of the galaxy (Fig.3). Such symmetrically Doppler-shifted emission has not been observed ever since the case of NGC 4258 (Nakai et al. 1993). The galaxy is quite a promising object to search for an accretion disk around an active nucleus.

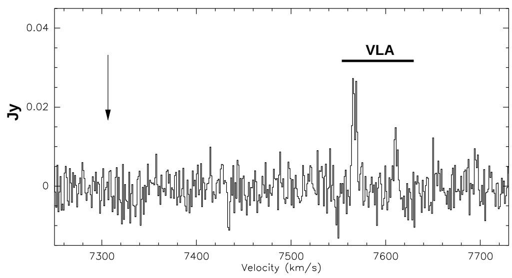

Fig. 1. Single-dish H_2O maser spectrum of NGC 6240 on 15 July 2001 (Hagiwara, Diamond, & Miyoshi 2002). Vsys is indicated by an arrow. The velocity range observed by the VLA in Fig.2 is marked by a thick line.

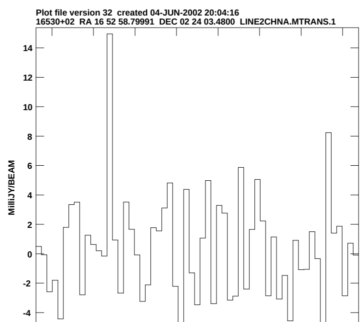

Fig. 2. The VLA maser spectrum of NGC 6240 in 5 August 2001. The 7565 km s^{-1} feature in Fig.1 is detected.

2. VLA/VLBA observations

Several VLA/VLBA observations are listed in Table 1. VLA (C configuration) spectrum in Fig.2 shows 4σ detection of $V_{\rm LSR}$= 7565 km s^{-1} feature, although which needs confirming. The tentative position of the maser is α(J2000) = $16^h52^m58^s.795$, δ(J2000) = 02°24'03".510. The continuum source at 22 GHz was imaged from line-free channels. The estimated position of the maser at $V_{\rm LSR}$= 7565 km s^{-1} is offset to west relative to the peak of the continuum emission. The distance between them is approximately a synthesized beam size of ~ 1.4 arcsec. The continuum peak is referred as a southern nucleus

Table 1. Observations of H_2O maser in NGC 6240

Telescope	Date	S_f(mJy)	T_b(K)
VLA (C)	5 Aug 2001	∼15	~ 20
VLA (D)	1 Oct 2001	∼15[a] ≤	$\sim 4 \leq$
VLBA	4 Oct 2001	18[a] ≤	$\sim 10^7 \leq$

[a] 3σ rms noise level per velocity channel of 1.3 km s^{-1}(VLA) and 1.6 km s^{-1}(VLBA)

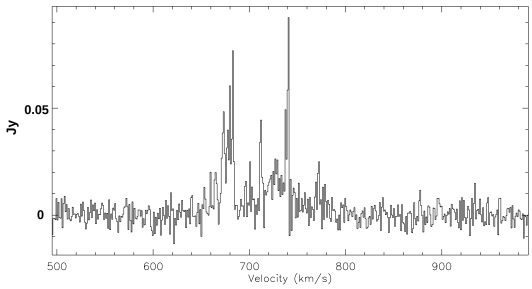

Fig. 3. Discovery spectrum of the H_2O maser emission from the Seyfert 1 galaxy on 4 March 2002 at Effelsberg, averaged over 2 days (Hagiwara et al. 2002). The spectrum shows a systemic component at $\sim$ 710 km $s^{-1}$and several distinct components on either side of the systemic component.

in the old literatures, which is believed to be a 'real' nucleus in the double-nuclei (e.g., Beswick et al. 2001). The more accurate maser position(s) by our undergoing VLA in B array observation will be comparable on similar angular scales with that(those) of hard X-ray obtained by the Chandra (Lira et al. 2002). Unfortunately, the VLBA observations did not detect any H_2O emission at an rms noise = 6 mJy/beam per velocity channel (1.6 km s^{-1}), that may be due to the fading of the maser itself. Non-detection of the emission by the VLA 3 days before the VLBA observations supports (Table 1) this hypothesis.

We measured the position of the maser from the Seyfert 1 with the VLA several weeks after the single-dish detection, as a result of that two velocity components are detected and remain unresolved at $\sim$ 0.1 arcsecond ($\sim$ or 5 pc, assuming D=9.7 Mpc) in the same position (Hagiwara et al. 2002). They correspond to two components in Fig.1, one of which is redshifted to V = 740 km s^{-1}, and the other is systemic component at V = 710 km s^{-1}. Both of the components coincide with the peak positions of radio continuum sources to $\sim$ 0.1 arcsecond that are observed at lower frequencies, suggesting that the maser is associated with an active nucleus of the galaxy, at least to 0.1 arcsecond scales. According to the preliminary analysis, no radio continuum emission at 22 GHz was detected. Before the emission becomes invisible, we wish to determine its position in milliarcsecond scales, and the structure of the nuclear region.

3. Origins of the maser emission

Though the position of the maser emission in NGC 6240 is tentative, the peak position is significantly displaced from the continuum nucleus to a synthesized beam, or 750 pc, adopting D = 97 Mpc. However, the unresolved H_2O emission seems to extend to western part of the southern nucleus. This is consistent to the idea that the H_2O maser is a nuclear maser and the "real" nucleus of the galaxy lies in the southern nucleus (e.g., Colbert et al. 1994). In addition, there observed hard X-ray points coincident with those of H_2O emission. The apparent isotropic luminosity of the maser was $\sim 40\ L_\odot$ when discovered, the value of which is one order magnitude larger than that of H_2O masers in starburst regions, i.e. H_2O kilomaser. The H_2O maser in NGC 6240 is thus more likely to be associated with AGN rather than star forming region, alternatively it is with both of them.

On the other hand, the positions of the maser in the other galaxy are coincident with those of continuum emission at lower frequencies to within 0.1 arcsecond, or 5 pc. The maser probably lies in the nucleus of the galaxy, suggesting that the excitation of the maser could be due to the central engine. The relatively lower velocity dispersion (30 – 50 km s^{-1}) of the velocity components w.r.t. the systemic component at 710 km s^{-1} may be due to the lower inclination of the rotating disk in the line of sight - observers might see a part of BLR obscured by the molecular material differently in the case of type 2 Seyferts or LINERS. If the maser arises from an edge-on disk around a nucleus, the velocity drift of the systemic component will be measured by analogy with the case of NGC 4258 (Miyoshi et al. 1995). Analysis of two velocity components over 2 epochs by the single-dish and VLA measurements results in non-detection of velocity change with an upper limit of 1.3 km s^{-1} over about seven weeks. With this fact, one can imagine that observers look at, if any, a maser disk surrounding BLR from relatively lower inclination. The peak position of the radio continuum sources shifts depending on observing frequencies (Lobanov 1998), and we need to register more accurate astrometric uncertainties to both the positions at higher frequencies with further VLBI observations. Our discovery of the H_2O maser from the Seyfert 1 galaxy is of great importance, which appears to break the mould.

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