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Extragalactic H_2O Megamaser Sources: Central Black Holes, Nuclear X-ray and Maser Emissions *

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Abstract Extragalactic H_2O megamasers are typically found within the innermost few parsecs of active galaxy nuclei (AGN) and the maser emission is considered to be excited most likely by the X-ray irradiation of the AGN. We investigate a comprehensive sample of extragalactic H_2O masers in a sample of 38 maser host AGN to check potential correlations of the megamaser emission with parameters of the AGN, such as X-ray luminosity and black hole (BH) masses. We find a relation between the maser luminosities and BH masses, $L_{\rm H_2O} \propto M_{\rm BH}^{3.6\pm0.4}$, which supports basically the theoretical prediction. The relation between the maser emission and X-ray emission is also confirmed.

Key words: galaxies: active — galaxies: nuclei — masers

1 INTRODUCTION

Maser (microwave amplification by stimulated emission of radiation) emission is one of common natural phenomena in the universe, for the interstellar medium has a much lower density than in terrestrial conditions and is typically out of thermal equilibrium, and the H_2O maser ($J_{\rm K_aK_c} = 6_{16} - 5_{23}$, $\lambda \sim$1.3 cm) is one of most common astrophysical masers. In the Galaxy, H_2O maser emission has been detected toward more than 1000 sources, since it was first detected toward Orion-KL, Sgr B2 and W49 (Cheung et al. 1969). Those masers originate in dense molecular gas in star formation regions (e.g., Lo 1974; Genzel et al. 1978) or the molecular circumnuclear stellar envelopes of evolved giant and super-giant stars (e.g., Johnston et al. 1985).

H_2O maser emissions have also been detected toward external galaxies, e.g., the first detection towards M33 (Churchwell et al. 1977). Besides the similar masers found in star formation regions of nearby galaxies, maser emissions were in particular, detected in the nuclear regions of active galaxies, with surprisingly large luminosities of $\sim 10^2$–$10^4\,L_\odot$, i.e., million times more luminous than typical Galactic H_2O maser sources. So, these masers are called “megamasers” ($L_{\rm H_2O} > 10 L_\odot$, e.g., Henkel et al. 2005a; Dos Santos & Lepine 1979). They apparently have different properties from the interstellar masers. Given their very high luminosities, these nuclear masers are considered to originate in circumnuclear dense clouds and the only possible energy source would be active galactic nuclei (AGN), rather than stars as in the case of the Galactic masers (Lo 2005). H_2O maser emission can occur in the accretion disks of supermassive black holes (BH, ‘disk maser’, Greenhill et al. 1995) and in shocks driven by jets and winds (‘jet maser’, Greenhill et al. 2002). Radio interferometric studies of these nuclear masers are the only means by which any structures ($<$1 pc) surrounding supermassive BHs can be mapped directly. This can help us to elucidate the properties of the innermost regions of AGN, such as the shape of accretion disk and the sub-parsec dynamical mass of the central massive BH, etc. (Morganti et al. 2004).

Observations show that H_2O megamaser spots are located preferentially in nuclei with high gas column densities ($N_{\rm H} < 10^{24}\,{\rm cm}^{-2}$, e.g., Zhang et al. 2006). Considering the obscuration of the optical emission,

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X-rays allow a penetrating view of these obscured H_2O megamaser sources. As mentioned above, the AGN is considered to be the ultimate energy source of the megamaser, since the AGN is located in the very compact central region of the galaxy which is very powerful and extremely luminous. Based on the unified model, a BH exists in the center and dominates the intense activity and strong radiation of the AGN by accretion and jets. X-rays from the AGN can heat up the circumnuclear dense gas through X-ray dissociation and ionization. Over a wide range of X-flux and gas pressure, the effect of X-ray heating is to give rise to a high density molecular layer of temperatures 400–1000 K, in which powerful, collisionally pumped H_2O masers (the $\sim$22 GHz transition of ortho-water) can exist, and the predicted maser luminosities are proportional to the illuminated area ($10^{2\pm0.5} L_\odot$ pc^{-2}) (Neufeld et al. 1994; Neufeld & Maloney 1995). Correlations could be expected between the mass of central engine, the X-ray emission from AGN and the maser emission.

In this paper, the whole extragalactic H_2O maser sources with their observation data are investigated and analyzed in order to probe possible relation between the maser emission, the X-ray emission, and the central engine of the maser host galaxy. The data for the whole extragalactic H_2O maser sample are presented in Section 2. A detailed statistical analysis is given in Section 3. Discussion and summary follow in Sections 4 and 5, respectively.

2 EXTRAGALACTIC H_2O MASER SAMPLE

The number of galaxies with maser emissions has greatly increased, thanks to the development of sensitive receivers and wide-band acoustic-optic spectrometer. To date, there are $\sim$ 100 known sources, of which 69 were reported in the March 2007, IAU 242 Symposium on Masers. We have investigated and collected the observational data and parameters, including maser isotropic luminosities, active types, BH masses of maser host galaxies, X-ray unabsorbed luminosities and velocity dispersions, etc. See Table 1.

In previous works various methods were used to estimate the BH masses of AGN (Xie et al. 2005; Bian et al. 2003). However, it was noticed that the BH masses obtained by different methods differed greatly, sometimes by a whole order of magnitude. In order to avoid such uncertainties in our statistical study, we used just one method to obtain the BH mass of the maser sources in our sample, i.e., the method based on the correlation of the BH mass and the stellar velocity dispersion ($M - \sigma$), taken from the literature. So the BH masses were derived using the formula, $\log(M_{\rm BH}/M_\odot) = \alpha + \beta \log(\sigma/\sigma_0)$, where σ is the velocity dispersion, α = 8.13, β = 4.02 and σ_0 = 200 km s^{-1} (Tremaine et al. 2002). The BH masses of 29 sources with available velocity dispersions were obtained by this method. For the other five sources (NGC 2782, NGC 4922, NGC 5256, NGC 591 and MRK 34), we calculated their velocity dispersions from the FWHMs (full widths at half maximum) of [OIII], with σ=FWHM([OIII])/2.35/1.34 (Greene & Ho 2005), and then estimated their BH masses from the $M - \sigma$ relation. So we obtained the BH masses for 34 maser sources for our statistical studies. For comparison, the BH masses derived from a variety of methods in the literature are also collected in Table 1.

The X-ray data for all maser sources were searched for in the *ASCA*, *BeppoSAX*, *XMM-Newton*, and *Chandra* X-ray observations. We obtained 31 sources with X-ray unabsorbed luminosities, 29 from Kondratko et al. (2006), and other two sources, NGC 253 and NGC 1068, from Maiolino et al. (2003) and Colbert et al. (2002), respectively.

The ranges of X-ray luminosities given in Table 1 were obtained after considering multiple observations in some sources with different fitting models and the uncertainty in the reflection efficiency for Compton-thick sources (absorbing column density larger than 10^{24} cm^{-2}).

In addition, we collected the data of isotropic maser luminosity for the whole maser sample. In Table 1, 38 of 64 sources with available maser luminosities are presented, for which either their X-ray luminosities or BH masses are listed. All these 38 masers are related to AGN, i.e., all referring to nuclear masers, including 33 megamsers and five kilomasers ($L_{\rm H_2O} < 10\, L_\odot$, NGC 253, NGC 4051, NGC 5194, NGC C2273 and NGC 6300, Henkel et al. 2005b; Kondratko et al. 2006; Zhang et al. 2006). For the nuclear masers, the AGN is considered as their ultimate energy source and possible correlation could be expected between the central engine and the maser emission.

Table 1 Physical Parameters of Extragalactic H_2O Maser Sources*

Name	Type[a)]	σ [b)]	$M_{\rm BH,S}$ [c)]	$M_{\rm BH,L}$ [d)]	$L_{\rm H_2O}^{\rm e)}$	$L_{\rm X}^{f)}$	Reference[g)]
NGC 253	SBG	109	6.68–7.39		-0.8	8.4	2
MRK 348	S2	118	6.85–7.50	7.9	2.6	8.9–10.4	3,11
NGC 449	S2	115	6.79–7.47	7.2	1.7		3,3
NGC 591	S2	95±8	6.68–6.98		1.4		7
NGC 1052	LINER	207±10	8.10–8.27	8.2	2.1	7.5–8.0	1,3
NGC 1068	S2	151±12	7.35–7.87	7.2	2.2	9.7–10.2	1,12
		160					2
		144±20					5
		165±12					4
MRK 1066	S2	105±15	6.74–7.24	7.0	1.5	9.0–9.2	1,3
NGC 1386	S2	120±30	6.74–7.63	7.2	2.1	8.4–9.0	1,3
MRK 3	S2			8.7	1.0	9.6–10.4	3
NGC 2273	S2	124±10	7.15–7.43	7.6	0.8	8.1–9.3	1,14
		124±10					4
MRK 78	S2	172	7.63–8.08	7.9	1.5		3,3
MRK 1210	S2	114±20	6.81–7.43		1.9	9.3–10.3	5
NGC 2639	LINER	195	7.92–8.24	7.9	1.4	7.0–8.1	10,14
NGC 2782	SBG	89±13	6.45–6.95	7.7	1.1	7.6–9.1	8,14
UGC 5101	ULIRG				3.2	8.8–9.8	
NGC 2979	S2	112±20	6.77–7.40		2.1		5
NGC 3079	LINER	150±10	7.51–7.74	∼6	2.7	8.4–9.4	4,13
MRK 34	S2	181±3	7.92–7.99		3.0		8
IC 2560	S2	144	7.27–7.80	6.4	2.0	8.3–9.2	5,13
NGC 3393	S2	157±20	7.47–7.92		2.4	8.5–10.2	5
NGC 3690	SBG				2.1	8.2–9.4	
NGC 4051	S1.5	88±13	6.42–6.94	6.1	0.3	7.6–8.5	1,12
NGC 4258	LINER	120	6.95–7.48	7.6	1.9	7.0–7.7	9,12
NGC 4388	S2	119	6.51–7.28	6.8	1.1	8.7–9.5	1,12
		111±20					5
		74±34					4
ESO 103-G012	S2	161±20	7.52–7.96		3.0		5
NGC 4922	S2	152±8	7.56–7.74		2.3		6
NGC 4945	S2	134	7.12–7.70	6.1	1.7	9.1–9.6	2,13
NGC 5194	S2	102±25	6.46–7.34	7.0	-0.2	7.7–8.4	1,12
MRK 266	S2	100±8	6.78–7.05		1.5	9.3–10.3	6
NGC 5347	S2	93±21	6.14–7.05	6.8	1.5	8.1–9.1	1,3
		93					3
		73±14					4
Circinus	S2	168	7.58–8.04	6.2	1.3	7.5–8.6	2,13
NGC 5506	S2	180	7.42–7.88	7.8	1.7	8.9–9.4	2,11
		98±20					5
		180±20					4
NGC 5643	S2	93±20	6.37–7.13		1.4	7.6–9.0	5
NGC 5728	S2	155±20	7.44–7.90		1.9	8.7–10.2	5
NGC 6240	LINER	300	8.70–8.96		1.6	9.8–10.8	2
NGC 6300	S2	100±20	6.53–7.24	5.4	0.5	8.1–8.5	5,15
ESO103-G035	S2	114±20	6.81–7.43		2.6	9.1–9.9	5
3C 403	FR II				3.3	9.6–10.3	

* Maser sources with available BH masses or X-ray luminosities are listed. a) Type of nuclear activity. SBG: Starburst Galaxy; S1.5, 1.9, S2: Seyfert type; LINER: Low-Ionization Nuclear Emission Line Region; ULIRG: Ultra Luminous Infrared Galaxy; FRII: Fanarov-Riley Type II galaxy. References: Zhang et al. (2006); Kondratko et al. (2006). b) Velocity dispersion (km s^{-1}). For sources with several values, the mean value was taken from our statistical study. For NGC 591, NGC 2782, MRK 34, NGC 4922 and MRK 266, the velocity dispersions are calculated from their published FWHMs of [OIII], see footnote g). c) BH masses obtained from velocity dispersions are used in our statistical study (in $\log M/M_\odot$). The ranges quoted here reflect the uncertainty in the velocity dispersion. d) BH masses from the literature (in $\log M/M_\odot$). e) Total isotropic H_2O maser luminosities are from Henkel et al. (2005b), while those of NGC 2273 and NGC 3393 are from Zhang et al. (2006). f) X-ray (2–10 keV) unabsorbed luminosities from Kondratko et al. (2006), while those of NGC 253 and NGC 1068 are from Maiolino et al. (2003) and Colbert et al. (2002), respectively. g) References for cols. b)(the former number) and d) (the latter). 1) Nelson et al. (1995); 2) Oliva et al. (1999); 3) Woo et al. (2002); 4) Wu (2007); 5) Cid Fernande et al. (2004); 6) Dahari et al. (1988); 7) Wang et al. (2007); 8) Wilson et al. (1990); 9) Gebhardt et al. (2000); 10) Pizzella et al. (2005). 11) Nikolajuk et al. (2004); 12) Panessa et al. (2006); 13) Ferrarese et al. (2005); 14) Dong et al. (2006); 15) Awaki et al. (2006).

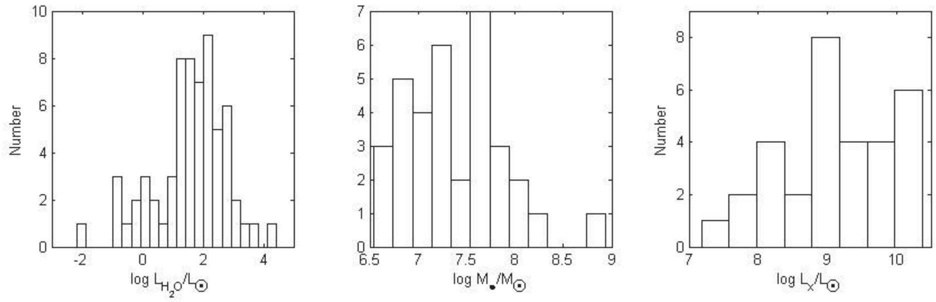

Fig. 1 Left: number distribution of isotropic luminosities of 64 extragalactic H_2O maser sources. Middle: number distribution of the BH mass of 34 H_2O maser host galaxies. Right: number distribution of unabsorbed X-ray (2–10 keV) luminosities of 31 extragalactic H_2O maser sources.

3 DATA ANALYSIS

We first investigate the distribution of some physical parameters of the maser sources in our sample. The number distribution of isotropic maser luminosity of all 64 sources is shown in the left panel of Figure 1. The X-axis represents the maser luminosity ranging from –2 to 4.4 (logarithmic value in units of solar luminosity, $\log L/L_\odot$). We note that the distribution is broad and has a low luminosity tail ($L_{\rm H_2O}$ $<10\,L_\odot$, consisting of 13 kilomaser sources), mainly associated with star forming regions. The mean values of logarithmic luminosity of the kilomasers and megamasers are $\langle\log L_{\rm H_2O}\rangle = -0.67 \pm 0.20$ and $\langle\log L_{\rm H_2O}\rangle = 2.09 \pm 0.10$, respectively, the uncertainties shown are the standard deviation of the mean.

For the 34 maser sources with available BH masses (derived from the $M - \sigma$ relation), the number distribution of the BH masses is displayed in the middle panel of Figure 1. The histogram shows the number of extragalactic H_2O masers as a function of the BH mass. The majority of the masses are in the range of 6.7–7.9 (logarithmic value, solar units, log$M/M_\odot$), the mean value and peak value are $\langle$log$M_{\rm BH}\rangle$ = 7.35 $\pm$ 0.09 and $\sim$7, respectively. The hidden broad line region Seyfert 2s (HBLR S2s) were considered to be ideal places for H_2O maser to occur. Wang & Zhang (2007) analyzed a sample of 243 nearby Seyfert galaxies and reported that the mean BH mass of 36 HBLR S2s is 7.31 $\pm$ 0.16 (log$M/M_\odot$). Our result is consistent with theirs.

The right panel of Figure 1 shows the number distribution of unabsorbed X-ray luminosities (2–10 keV) of those 31 sources have well defined X-ray spectra. It can be seen that the X-ray luminosities are sampled from 7.4 to 10.5 (log$L/L_\odot$), with peak value at $\sim$ 9 and mean value $\langle\log L_{\rm x}\rangle$ = 9.12 $\pm$ 0.14.

3.1 X-ray Luminosities and H_2O Maser Luminosities

According to the model proposed by Neufeld et al. (1994), extragalactic nuclear H_2O masers are excited by X-ray emissions from AGN, so these maser emissions may be correlated with the emissions of nuclear X-ray sources. Braatz et al. (1997) investigated this possibility but found no correlation. However this result was based on only seven H_2O maser sources and the relatively coarse X-ray data from $EXOSAT, GINGA$ and $ASCA$ (Advanced Satellite for Cosmology and Astrophysics) telescopes. With the development of X-ray telescopes and substantial increase in the number of known H_2O masers, the relation was re-analyzed by Kondratko et al. (2006). With 30 nuclear H_2O masers with available unabsorbed X-ray luminosities (2–10 keV), a possible relation was found between the X-ray luminosities and total isotropic H_2O maser luminosities ($L_{2-10} \propto L_{\rm H_2O}^{0.5\pm0.1}$), and the authors presented possible reasons for the scatter in the fitting results, such as the mass accretion rate and the ratio of X-ray luminosity to bolometric luminosity.

Actually, maser emissions are always variable and multiple observations may exist for the same source. To test the assumed relation from Kondratko et al. (2006), we checked the observational data in more details in all the maser sources, including the X-ray luminosity and maser luminosity. Different values were reported for some sources in the literature (Data from different telescopes or different times of observation). For example, Kondratko et al. (2006) reported the H_2O maser luminosities of NGC 1068, NGC 3079,

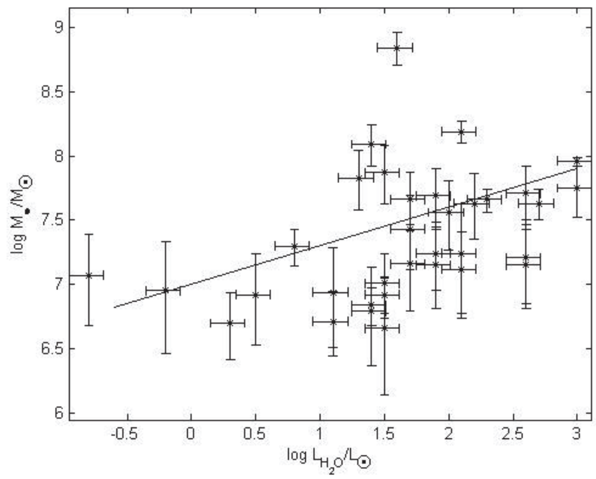

Fig. 2 Total isotropic H_2O maser luminosities versus BH masses. Vertical error bars indicate the range of estimated masses. Horizontal error bars (± 30 percent of luminosity) indicate the range of H_2O maser luminosities. The solid line shows the result of a linear fit.

NGC 3393, NGC 5643 and NGC 6300 as 1.7, 2.5, 2.4,1.3 and 0.34 (log$L/L_\odot$), respectively, whereas Zhang et al. (2006) and Henkel et al. (2005b) reported values: 2.2, 2.7, 2.6, 1.4 and 0.5 (log$L/L_\odot$), respectively. In a separate work the X-ray luminosity of NGC 253 was reported as 8.4 (log$L/L_\odot$) (Maiolino et al. 2003). Taking into account these differences, we re-analyzed the correlation and obtained $L_{2-10} \propto L_{\mathrm{H_2O}}^{0.39\pm0.15}$, showing that these details have little influence on the relation derived by Kondratko et al. (2006).

3.2 Black Hole Masses and H_2O Maser Luminosities

Here we explore the possible relation between the H_2O maser luminosity and the BH mass of the host galaxy, for which we have the BH masses of 34 sources from the M-σ relation. The BH masses are plotted against the isotropic luminosities of H_2O maser (Fig. 2). A $\pm30\%$ uncertainty is taken in the maser luminosities. The uncertainties of BH masses originate from errors in the FWHM of [OIII] and velocity dispersions. For all these 34 sources, a linear fitting gives logM_{BH} =(0.25±0.09)log$L_{\mathrm{H_2O}}$ + (6.97±0.14), with a correlation coefficient ρ = 0.42. Taking the error bars into account, the fitting result becomes logM_{BH} = (0.28±0.03)log$L_{\mathrm{H_2O}}$ + (7.12±0.08), with a correlation coefficient ρ = 0.50.

We tried to analyze this possible relation by a further consideration of the different types of masers. We discarded four LINERs (NGC 2639, NGC 3079, NGC 4258 and NGC 6240), because they have a broader range of Eddington ratio, three galaxies with multiple nuclei (MRK 266, NGC 6240, MRK 1066) for which it is uncertain that the nucleus is responsible for the maser emission, and two masers associated with a nuclear outflow and jets (NGC 1052, MRK 348) because the model proposed by Neufeld et al. (1994) is unsuitable for them. For the remaining 25 sources, we made the fitting again, following Kondratko et al. (2006). The result is logM_{BH}= (0.26±0.07)log$L_{\mathrm{H_2O}}$ + (6.86±0.13), with a correlation coefficient ρ = 0.60. Then with the uncertainties considered, we obtained logM_{BH} = (0.43±0.03) log$L_{\mathrm{H_2O}}$ + (6.64±0.09), with a larger correlation coefficient of ρ = 0.88. Moreover, since the 'disk masers' are located in the circumnuclear molecular disk, a stronger correlation could be expected between the nuclear engine and maser emission (Neufeld & Maloney 1995). However, there are only seven 'disk masers' with available BH masses and these did not show any obvious trend. Future high-resolution VLBI mapping of more 'disk masers' will be useful for the determination of their BH masses and for further investigation of the excitation of nuclear H_2O masers.

In addition, different BH mass values from different methods were collected from the literature (see col. 5 of Table 1) and were tested for the relation, to check how much this correlation depends on the BH mass values from different methods. We obtained a weak relation of $\log M_{\rm BH}$ = (0.14±0.19)$\log L_{\rm H_2O}$ + (0.47±1.36), with a correlation coefficient ρ = 0.16. BH masses from different methods do seriously affect the relation. Currently a majority of BH masses of AGN were derived from the empirical M-σ relation. This method should be good, since it avoids the uncertainties arising from considering the inclination of the broad line region. Reverberation mapping may be another reliable method, but it is always time consuming. Anyway the evaluation of different methods for estimating BH mass is really important and desirable.

4 DISCUSSION

VLBI observations of H_2O maser emission from NGC 4258 revealed a disk structure around the nucleus, viewed edge on, which orbits a central BH and radiates maser emission (Greenhill et al. 1995). *ASCA* observations of NGC 4258 also indicate the existence of a central X-ray source which illuminates obliquely a warped disk (Makishima et al. 1994). Kondratko et al. (2006) presented a possible relation between the X-ray luminosities and the total isotropic H_2O maser luminosities (Sect. 3.1). Neufeld & Maloney (1995) analyzed the physical conditions within the disk and determined a critical outer radius of the mass accreting annulus outside which the disk is atomic throughout, $R_{\rm cr} \propto L_{2-10}^{-0.43}(\dot{M}/\alpha)^{0.81}\mu^{-0.38}M_{\rm BH}^{0.62}$, where L_{2-10} is the X-ray (2–10 keV) luminosity, $\dot{M}$ the mass accretion rate, α the viscosity parameter, μ the angle at which the central X-ray source illuminates the disk and $M_{\rm BH}$ the BH mass. The X-ray heated molecular disk emits H_2O maser radiation with a surface luminosity $\sim 10^{2\pm0.5} L_\odot$ pc $^{-2}$ of the illuminated area, and the maser luminosity is proportional to $R_{\rm cr}^2$ (Neufeld et al. 1994):

$$L_{\rm H_2O} \propto R_{\rm cr}^2 \propto L_{2-10}^{-0.86}(\dot{M}/\alpha)^{1.62}\mu^{-0.76}M_{\rm BH}^{1.24}. \quad (1)$$

Given the rest mass to energy conversion efficiency $\epsilon = L_{\rm Bol}/\dot{M}c^2$ (Frank et al. 2002; Kong et al. 2004) and the relation between nuclear bolometric luminosity and Eddington luminosity $L_{\rm Bol} = \eta L_{\rm Edd} \propto \eta M_{\rm BH}$, the relation of mass accretion rate and BH mass can be derived (similar to Kondratko et al. 2006),

$$\dot{M} \propto \eta M_{\rm BH}/\epsilon c^2. \quad (2)$$

Furthermore, given the X-ray (2–10 keV) luminosity as a part of the AGN bolometric luminosity (L_{2-10} = $\gamma L_{\rm Bol}$) and the ratio of Eddington luminosity to AGN bolometric luminosity ($L_{\rm Bol} = \eta L_{\rm Edd} \propto \eta M_{\rm BH}$), we obtain

$$L_{2-10} \propto \eta\gamma M_{\rm BH}. \quad (3)$$

Eliminating $\dot{M}$ and L_{2-10} of Equation (1), the H_2O maser luminosity is

$$L_{\rm H_2O} \propto M_{\rm BH}^2 \eta^{0.76}\gamma^{-0.86}(\epsilon\alpha)^{-1.62}\mu^{-0.76}. \quad (4)$$

From our previous analysis of the H_2O maser sample, we obtained a correlation of $\log M_{\rm BH} = (0.28 \pm 0.03)\log L_{\rm H_2O} + (7.12 \pm 0.08)$ (Sect. 3.2). It is comparable to the theoretical results, although the slope deviates a little bit. In addition, the M-σ relation method may be one of the most reliable methods to determine the BH mass of AGN due to the strong dependence of the relation on the BH mass values in our analysis.

The cause of the deviation in the slope is less clear. First, there is the considerable uncertainties in the values of BH masses, although a uniform method ($M - \sigma$ relation) was used. Secondly, uncertainties also exist in the H_2O maser luminosities. Maser emissions are always variable and different observations may give different results. The maser emission is assumed to be isotropic, whereas it is, in fact, confined to a small beam angle which may be different from source to source. In addition, the parameters $\alpha, \eta, \epsilon, \gamma$ and μ in different sources may differ. These factors can cause the deviation of the fitting result from the theoretical result. It would be interesting to check the relation, taking into account the difference of these physical parameters.

As a deeper consideration, diversity of the megamaser configuration can also weaken the correlation between BH masses and maser emissions. As mentioned above, megamsers can be classified into 'disk masers' (maser emission from the circumnuclear disk) and 'jet masers' (associated with radio jet), and the 'disk masers' can be further divided into two types, Type-A maser (without or with weak Fe line, possibly originating in the thin molecular disk) and Type-B (with strong Fe line, possibly from thick molecular disk).

Comparing with the 'jet masers', the 'disk masers' should be expected to have a stronger correlation with the central BH masses. Also, the mass accretion rate $\dot{M}$ is found smaller in type-A megamasers than that in type-B (Yamauchi 2005).

Although there are many uncertainties surrounding the relation between the central engine and H_2O megamsers emission, further study of their correlation would be desirable and valuable. If the correlation is really verified and strengthened, it should be one of ideal methods to estimate the BH mass and to further evaluate the other methods. The future SKA (square kilometer array) and space interferometry (orders of magnitude improvement in sensitivity and angular resolution) will increase the number of known H_2O megamsers to 10^{4-5} and will map maser disk structures in more details. Higher quality X-spectra are also required to penetrate through the circumnuclear gas environment. Many key questions are expected to be resolved, including the excitation mechanism of H_2O megamsers, the physical environment of the nuclear regions, the BH masses, and accurate distances of galaxies.

5 CONCLUSIONS

In this paper, H_2O maser emissions and BH masses of maser host galaxies are investigated for most published extragalactic H_2O maser sources. We have collected the observation data and physical parameters of a sample, including the BH masses, X-ray luminosities, maser isotropic luminosities and velocity dispersions, etc. In order to avoid uncertainties in the statistical analysis, we used BH masses obtained from the same method, i.e., the $M-\sigma$ relation. From the analysis we obtained the correlation between maser luminosities and BH masses, $L_{\rm H_2O} \propto M_{\rm BH}^{3.6\pm0.4}$, which supports to some extent, the theoretical results, $L_{\rm H_2O} \propto M_{\rm BH}^{2}\, \eta^{\,0.76}\, \gamma^{\,-0.86}\, (\epsilon\alpha)^{\,-1.62}\, \mu^{\,-0.76}$. However, the strong dependence of the relation on the BH mass in our analysis supports the suggestion that the empirical $M-\sigma$ method is one of the most reliable methods to determine the BH masses. Based on more detailed data, the possible relationship between unabsorbed X-ray luminosity (2–10 keV) and isotropic luminosity of H_2O maser supposed by Kondratko et al. (2006) is confirmed here.

Further verification of the putative correlation between maser emission and the central engine would be required and valuable. It may provide a good new method to determine the BH masses of maser host galaxies, and further explore the innermost regions of megamaser galaxies.

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