Cosmic MASERs: From Protostars to Blackholes
IAU Symposium, Vol. 206, 2002
V. Migenes and M. J. Reid, eds

IR properties of H_2O megamaser galaxies, pumping mechanisms, and central sources

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Abstract. The IR-properties of all the host galaxies which exhibit H_2O megamaser emission have been studied in this paper. The most striking feature is the anticorrelation of the log[S(60)/S(100)] vs. log[S(12)/S(25)] and log[S(25)/S(60)] vs. log[S(12)/S(25)], and the correlation of log[S(60)/S(100)] vs. log[S(25)/S(60)]. These anticorrelations and the correlation in the flux density ratios can be explained by the coexistence of large and very small dust particles. The relationship between the luminosity of the H_2O megamaser and the infrared luminosity vs. the flux density ratio of S(60)/S(100), S(25)/S(60), and S(12)/S(25) have been studied. The correlation of the luminosity vs. S(60)/S(100) and the luminosity vs. S(25)/S(60), and the anticorrelation of the lumonosity vs. S(12)/S(25) are obtained, respectively. The pumping mechanism of the H_2O megamaser is discussed according to the these results. The characteristics of the central sources are also studied, according to these relationships.

1. Introduction

The water-vapor megamasers, which have been found in the central region of galaxies, are as much as 10^6 times more luminous than the masers found in galactic star-forming regions. Recent surveys of H_2O megamasers of the 6_{16} - 5_{23} transition toward active galactic nuclei (AGNs) have been strongly motivated by several cases in which the megamasers probably trace the structure and dynamics of parsec-scale molecular disks bound by the central engines. There are 18 H_2O megamasers known in AGNs. A statistical analysis of results from those surveys, including all previous detections, indicates a detection rate of ~ 7 percent among 216 Seyfert 2 nuclei and LINERs, with no megamasers occurring in Seyfert 1 nuclei (Braatz, Wilson, & Henkel 1997). Also, no megamasers have been found in normal galaxies (cf, Braatz et al. 1996).

With the IRAS point source catalog it is now, for the first time, possible to investigate regions of high infrared luminosity in a systematic way. Active galaxies are known to be powerful infrared sources, and in many cases the mid-infrared emission of an AGN dominates its energy output. Still, the detailed processes that determine the infrared properties of AGNs are poorly understood. The emission at mid-infrared wavelengths (12 μm and 25 μm) are strongly related to more energetic photons by dust near the central engine. The far-infrared emission (60 μm and 100 μm), on the other hand, can be a tracer of dust heated in star-forming regions. Ongoing star formation is often seen in active galaxies and so may contribute to the far-infrared luminosity.

All 18 known H_2O megamasers have been found in the nuclei of galaxies which have some level of nuclear activity. They exist in Seyfert 2 galaxies or LINERs. The results suggest that H_2O megamasers are related to the nuclear activity of their host galaxies. The infrared properties of the H_2O megamaser galaxies have been studied in this paper.

2. Analysis of data

Dos Santos & Lepine (1979) discovered a luminous H_2O maser (several orders of magnitude more powerful than a typical Galactic maser) in the active galaxy NGC 4945. The H_2O megamasers have been found in the central regions of galaxies which have some level of nuclear activity. Although almost all of H_2O megamasers exist in Seyfert 2 galaxies or LINERs, no H_2O masers have been detected in galaxies definitely classified as Seyfert 1 galaxies. Also, no megamasers have been found in normal galaxies. These results suggest that the H_2O megamasers are related to the nuclear activity of their host galaxies.

Table 1 lists the basic parameters of all 18 known megamasers and IRAS properties of the host galaxies (Braatz et al. 1996, 1997; Greenhill et al. 1997; Hagiwara et al. 1997). What are the infrared-properties of the H_2O megamaser galaxies? What is the relation between the infrared-properties and the occurrence of detectable H_2O emission? We have prepared figures, which display the logarithm flux density ratio of log [S(25)/S(60)] vs. log [S(12)/S(25)], the logarithm flux density ratio of log [S(60)/S(100)] vs. log [S(12)/S(25)], the logarithm flux density ratio of log [S(60)/S(100)] vs. log [S(25)/S(60)], respectively. According to Table 1 some values are taken as the maximum in the figures. The most striking feature of these diagrams is the anticorrelation of log [S(60)/S(100)] vs. log [S(12)/S(25)], and log [S(25)/S(60)] vs. log [S(12)/S(25)], and the correlation of log [S(60)/S(100)] vs. log [S(25)/S(60)], respectively. Only one source is not displayed in the figures, because of its unknown 12 μm flux density. Thus we find two extremes: galaxies with relatively flat infrared spectra [large S(12)/S(25) and small S(60)/S(100)] and galaxies with steep spectra [small S(12)/S(25) and large S(60)/S(100)].

The anticorrelation in the flux density ratio can be explained by the coexistence of large and very small dust particles. The very small grains which are transiently heated by single photon absorption are believed to be responsible for the bulk of the 12μm radiation. When the photon energy density of the host galaxy is small, this implies a large S(12)/S(25) and a small S(60)/S(100). However, when the photon energy density becomes larger, the infrared spectrum will peak at wavelengths $\leq$ 100 μm thus enhancing the emission at 25 μm. As a consequence, smaller S(12)/S(25) and large S(60)/S(100) is observed. This effect might be enhanced by the destruction of small grains due to shock waves occurring near regions of massive star formation.

According to the suggestion by Genzel and Downes (1979) and Jaffe et al. (1981) the relation $L(H_2O) \sim 10^{-9}$ L_{IR} (infrared luminosity) holds not only for galactic but also for extragalactic sources. Thus using Table 1 we can obtain maps for the S(60)/S(100) vs. L_{IR} or $L(H_2O)$, S(25)/S(60) vs. L_{IR} or $L(H_2O)$, and S(12)/S(25) vs. L_{IR} or $L(H_2O)$. From the maps it is found that the L_{IR} or $L(H_2O)$ is correlated with S(60)/S(100) and S(25)/S(60), and anticorrelated with S(12)/(25), respectively. Thus, they tend to have relatively large S(60)/S(100) suggesting heating of dust by bursts of star formation or by a more exotic process, involving the active nucleus.

From linear fits to the maps of the sources we obtained that $S(60)/S(100) = 1.39 \times 10^{-11} L_{IR} - 1.17$, $S(25)/S(60) = 0.57 \times 10^{-11} L_{IR} - 0.36$, and $S(12)/S(25) = -0.54 \times 10^{-11} L_{IR} + 1.24$, respectively. If we assume dust grains are ideal black-body cubes, l represents its edge length, and the exterior-surface area is l^2 for every dust grain. Assuming the source is a sphere having radius R, n_g represents the density of the dust grain in terms of the surface area of the source sphere, and T_g represents the temperature of the dust grain, thus $L_{IR} = 4\pi R^2 n_g l^2 \sigma T_g^4$, where σ represents the Stephanian-Boltzmann constant. So we obtain $S(60)/S(100)=17.5\times 10^{-11} R^2 n_g l^2 \sigma T_g^4 - 1.17$, $S(25)/S(60)=7.15\times 10^{-11} R^2 n_g l^2 \sigma T_g^4 - 0.36$, $S(12)/S(25)=-6.78\times 10^{-11} R^2 n_g l^2 \sigma T_g^4 + 1.24$, respectively.

The megamaser emission associated with molecular gas in the inner torus suggests that the pumping agent is not a powerful shock driven out by the central source but rather many localized pump sources within the torus. Multiple pumping sources are also required to account for the whole velocity width of the maser emission. Such a picture is supported by the short term variability of individual features. Standard water vapor pumping schemes depend on shocks to provide a collisional pump. The simple model proposed earlier to explain the periodic variation involves a foreground masering shell being shock–pumped by a variable star, which in turn amplifies the nuclear continuum source. The X-ray emission from the nucleus could lead to a layer of excited water molecules in a shielded region of the molecular circumnuclear torus, as well as a population inversion of the 1.35-cm transition. The nuclear mass and the size of the radio source deduced from the H_2O data strongly suggest the presence of a massive compact structure in the nucleus.

This work was supported by the Chinese National Fundation of Natural Sciences and the Union Lab of Radio Astronomy, Chinese Academy of Sciences.

3. References

Braatz, J. A., Wilson, A. S., and Henkel, C., ApJS, 1997, 110, 321.
Braatz, J. A., Wilson, A. S., and Henkel, C., ApJS, 1996, 106, 51.
dos Santos, P. M. & Lepine, J. R. D., Nature, 1979, 278, 34.
Genzel, R. & Downes, D., A&A, 1979, 72, 234.
Greenhill, L. J. et al., ApJ, 1997, 486, L15.
Hagiwara, Y. et al., PASJ, 1997, 49, 171.
Jaffe, D. T., Gusten, R., Downes, D. ApJ, 1981, 250, 621.

Table 1. The basic parameters of all 18 known megamasers and IRAS properties of the host galaxies (Braatz et al. 1996, 1997; Greenhill et al. 1997; Hagiwara et al. 1997)

source	V_{sys} (km/s)	peak flux (Jy)	L_{maser} ($L_\odot$)	S(12) (Jy)	S(25) (Jy)	S(60) (Jy)	S(100) (Jy)	class
Mrk 1	4842	0.06	64	≤0.19	0.87	2.53	2.92	Seyfert 2
NGC1052	1507	0.21	140	0.20	0.49	0.90	1.52	LINER
NGC1068	1137	0.67	170	39.70	85.04	176.20	224.00	Seyfert 2
NGC1386	864	0.65	120	0.49	1.43	5.4	9.64	Seyfert 2
Mrk 1210	4046	0.16	99	0.50	2.08	1.89	1.30	Seyfert 2
NGC 2639	3336	0.11	71	0.16	0.21	1.99	7.06	LINER
NGC 3079	1125	11	520	1.52	2.27	44.50	89.22	LINER
IC 2560	2873	0.19	130	0.30	0.94	3.24	6.11	Seyfert 2
NGC 4258	448	6.2	85	2.25	2.81	21.60	78.39	LINER
NGC 4945	560	6.2	57	3.95	14.45	359.3	620.50	Seyfert 2
NGC 5347	2386	0.03	32	0.31	0.96	1.42	2.64	Seyfert 2
Circinus	438	16	24	18.80	68.44	248.70	315.85	Seyfert 2
NGC 5506	1815	0.63	61	1.28	3.64	8.41	8.89	Seyfert 2
ESO103-G35	3983	0.41	360	0.61	2.36	2.31	1.05	Seyfert 2
IC 1481	6118	0.35	320	≤0.13	0.28	1.41	1.51	LINER
TXFS2226-184	7500	0.27	6100	≤0.12	≤0.22	0.31	0.57	Radio Galaxy
NGC 5793	3442	0.05	125		0.45	6.36	8.65	Seyfert 2
NGC 3735	2696	0.016		0.66	1.03	6.7	18.4	Seyfert 2