A Study of Megamaser Galaxies

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Abstract The infrared property of megamaser galaxies, and its relationship with the observational characters of the OH megamasers are studied.

Key words galaxy:OH megamaser—OH luminosity—infrared luminosity

1 Introduction

OH megamasers are the most luminous cosmic maser sources known. The first extragalactic OH emission was detected in NGC253 (Whiteoak and Gardner 1973) and in M82 (Nguyen-Q-Rieu et al. 1976). The more powerful OH megamasers occur only in very luminous infrared sources, for example IC4553 (Baan, Wood and Haschick 1982). So far powerful OH maser emission has been discovered from 90 external galaxies (Baan et al. 1998; Darling & Giovanlli 2000; Darling & Giovalli 2001; Henkel & Wilson 1990; Phillips et al. 1998; Staveley-Smith et al. 1992; Yu 1991). An important observational character of OH megamaser sources is the relationship between OH luminosity L(OH) and infrared luminosity L(IR). We have tabulated L(OH) of only 66 OH megamaser sources among the 90 OH megamaser sources in Table 1 (Baan et al. 1998; Darling & Giovanelli 2000; Darling & Giovanelli 2001; Henkel & Wilson 1990; Phillips et al. 1998; Staveley-Smith et al. 1992; Yu 1991). The Hubble constant was taken as $75\,\mathrm{kms^{-1}Mpc^{-1}}$ in our calculations. We assume that emission was isotropic (Baan 1989), so single dish data from different measurements are comparable.

2 Relationship between L(OH) and L(IR)

The scenario of amplification requires a galaxy with a large molecular column density toward the central radio source. Such an edge-on situation may be needed in absorption or emission depending on the excitation state of the molecular gas. Meantime all galaxies with OH megamaser radiation have strong IR radiation. A quadratic $L(\mathrm{OH})-\mathrm{L(IR)}$ relationship rather than a linear one, i.e. $L(\mathrm{OH}) \sim \mathrm{L(IR)}^2$, is found for the observed megamasers by Baan(1989) using the parameters of 18 OH megamaser galaxies. However, accounting for Malmquist bias Kandalian(1996) obtained that the relationship between $L(\mathrm{OH})$ and $L(\mathrm{IR})$ was close to linear after reanalyzing the IR and OH data of 49 OH megamaser galaxies, the relationship is as follows: $\log L(\mathrm{OH}) = 1.38 \log \mathrm{L(IR)} - 14.04$, i.e. $L(\mathrm{OH}) \sim \mathrm{L(IR)}^{1.38}$.

Methods for correction of the Malmquist effect have been discussed by e.g. Kandalian 1996. We make use of the partial correlation coefficient method. The dependence of $\log L(\mathrm{OH})$ on $\log L(\mathrm{IR})$ for the 66 samples is as follows: With no-consideration of the Malmquist effect, the regression line with slope 1.71 is obtained using 1-D least-squares fits. With consideration of the Malmquist effect, the slope of line is 1.41 ± 0.11, and correlation coefficient is 0.58±0.02. The intercept of the regression line is -14.18±0.12. $S_R(\sigma)$ is 4.77. It means the confidence level of the correlation coefficient is greater than $3\sigma(\geq 99.7$ percent). Finally the regression equation is obtained as follows:

$$\log L(\mathrm{OH}) = (1.41 \pm 0.11) \log L(\mathrm{IR}) - 14.18\,,$$

i.e.

$$L(\mathrm{OH}) \sim \mathrm{L(IR)}^{1.41 \pm 0.11}\,.$$

The index is between Baan(1989) and Kandalian(1996), and closes to Kandalian(1996). For the complete sample of 66 extragalactic masers, it become clear that the $L(\mathrm{OH}) \sim \mathrm{L(IR)}^{1.41}$ distribution is more appropriate in describing the $L(\mathrm{OH}) \sim \mathrm{L(IR)}$ relationship.

Table 1 The values of D, $\log L(\mathrm{OH})$ and $\log L(\mathrm{IR})$ of the 66 OH megamaser sources

IRAS name	D (Mpc)	$\log L(\mathrm{OH})$ ($L_\odot$)	$\log L(\mathrm{IR})$ ($L_\odot$)	IRAS name	D (Mpc)	$\log L(\mathrm{OH})$ ($L_\odot$)	$\log L(\mathrm{IR})$ ($L_\odot$)
00057+4021	168	1.9	12.3	01418+1651	109.9	2.7	11.4
02483+4302	208	2.5	11.5	03260-1422	172	2.0	11.2
04121+0223	514	2.3	11.6	04332+0209	48	0.5	10.1
05100-2425	133.4	2.0	11.0	05414+5840	65.3	0.8	11.1
06487+2208	618	2.86	12.0	07163+0817	470	2.35	11.5
07572+0533	757	2.71	11.9	08201+2801	731	3.42	12.0
08279+0956	925	3.19	11.9	08449+2332	653	2.56	11.8
08474+1813	626	2.67	11.9	09039+0503	535	2.8	11.8
09320+6134	159	1.6	11.7	09531+1430	958	3.38	11.8
09539+0857	554	3.45	10.5	10039-3338	135	2.6	10.5
10173+0828	201	2.7	11.5	10339+1548	868	2.62	13.0
11010+4107	146	2.0	11.3	11028+3130	879	2.94	12.1
11257+5850	41.3	1.3	11.0	11506-3851	41.4	1.4	11.0
11524+1058	782	2.95	11.9	12018+1941	738	2.7	12.1
12032+1707	967	4.11	11.3	12112+0305	290	3.3	12.0
12243-0036	29.5	-0.1	10.7	12540+5708	170	2.9	12.1
13097-1531	91.1	1.0	11.2	13254+4754	245	1.9	11.2
13428+5608	152	2.7	11.9	15107+0724	51.7	1.0	11.0
15224+1033	577	3.01	11.5	15247-0945	160	2.1	11.3
15250+3609	219	2.6	11.7	15327+2340	73	2.7	11.9
15587+1609	589	3.23	11.6	16100+2527	559	2.26	11.5
16255+2801	572	2.54	11.7	16300+1558	1080	2.81	12.5
16399-0937	107	1.6	11.2	17208-0014	171	3.0	12.2
17539+2953	456	1.74	11.6	18368+3549	489	2.83	12.0
18588+3517	447	2.5	11.7	20100-4156	516	4.0	12.3
20248+1734	508	2.51	11.7	20286+1846	571	3.38	11.8
20450+2140	542	2.21	11.6	20550+1656	145	2.2	11.6
21077+3358	763	3.23	11.9	21272+2514	643	3.63	11.9
22025+4205	58.7	0.7	10.7	22055+3024	534	2.71	11.9
22116+0437	775	2.74	11.9	22491-1808	309	2.4	11.9
23019+3405	450	2.1	11.7	23028+0725	637	3.26	11.7
23129+2548	774	3.24	12.2	23135+2516	108	0.8	11.2
23199+0123	578	2.35	11.6	23234+0946	539	2.72	11.9

3 Infrared Characters of Host IRAS Sources with OH Megamasers

What is the infrared-properties of the host IRAS sources with OH megamasers? What is the relationship between the infrared-properties and the occurrence of detectable OH megamaser emission? We have obtained the infrared parameters of the only 62 host IRAS sources from the 66 samples. The infrared parameters are shown in Table 2.

Table 2 The infrared parameters of the 62 host sources with OH megamaser

IRAS name	$\frac{S(12)}{S(25)}$	$\frac{S(25)}{S(60)}$	$\frac{S(60)}{S(100)}$	IRAS name	$\frac{S(12)}{S(25)}$	$\frac{S(25)}{S(60)}$	$\frac{S(60)}{S(100)}$
00057 + 4021	0.65	0.08	0.95	01418 + 1651	0.23	0.08	0.96
02483 + 4302	1.0	0.056	0.60	03260 − 1422	1.0	1.07	0.68
04121 + 0223	1.12	0.27	0.57	04332 + 0209	0.23	0.27	0.93
05100 − 2425	0.73	0.08	0.82	05414 + 5840	0.7	0.07	0.47
06487 + 2208	0.48	0.25	0.88	07163 + 0817	0.96	0.29	0.65
07572 + 0533	0.96	0.27	0.73	08201 + 2801	0.98	0.22	0.71
08279 + 0956	1.07	0.43	0.63	08449 + 2332	0.65	0.77	0.73
08474 + 1813	0.63	0.29	0.08	09039 + 0503	0.68	0.25	0.65
09320 + 6134	0.24	0.09	0.6	09531 + 1430	0.78	0.42	0.76
09539 + 0857	0.77	0.23	1.05	10039 − 3338	0.25	0.13	1.04
10173 + 0828	0.47	0.09	1.05	10339 + 1548	0.76	0.33	0.67
11010 + 4107	0.66	0.06	0.57	11028 + 3130	0.73	0.12	0.71
11257 + 5850	0.17	0.2	0.95	11506 − 3851	0.25	0.07	0.77
11524 + 1058	1.31	0.4	0.63	12018 + 1941	0.92	0.17	0.88
12032 + 1707	0.51	0.34	0.97	12112 + 0305	0.4	0.08	0.84
12243 − 0036	0.1	0.22	1.3	12540 + 5708	0.22	0.25	0.12
13097 − 1531	0.35	0.08	0.51	13254 + 4754	1.0	0.14	0.66
13428 + 5608	0.13	0.1	1.06	15107 + 0724	0.31	0.04	0.69
15224 + 1033	0.55	0.17	1.02	15247 − 0945	0.67	0.08	0.73
15250 + 3609	0.19	0.18	1.28	15327 + 2340	0.06	0.08	0.88
15587 + 1609	1.5	0.3	0.82	16100 + 2527	0.98	0.12	0.52
16255 + 2801	2.0	0.28	0.62	16300 + 1558	0.93	0.17	0.79
16399 − 0937	0.33	0.13	0.67	17208 − 0014	0.15	0.05	0.95
18368 + 3549	1.0	0.11	0.58	18588 + 3517	1.3	0.1	1.02
20100 − 4156	0.6	0.08	1.04	20248 + 1734	1.0	0.34	0.29
20286 + 1846	1.0	0.27	0.41	20450 + 2140	1.0	0.34	0.14
20550 + 1656	0.13	0.17	1.13	21077 + 3358	1.57	0.28	0.57
21272 + 2514	0.92	0.36	0.66	22025 + 4205	0.35	0.74	0.67
22055 + 3024	1.23	0.13	0.8	22116 + 0437	1.08	0.37	0.9
22491 − 1808	0.44	0.1	1.19	23129 + 2548	1.0	0.14	1.06
23135 + 2516	0.18	0.18	0.8	23234 + 0946	0.28	0.13	0.74

We find two extremes: sources with relatively flat infrared spectra of [large $S(12\,\mu\mathrm{m})/S(25\,\mu\mathrm{m})$ and small $S(60\,\mu\mathrm{m})/S(100\,\mu\mathrm{m})$], and sources with steep spectra of [small $S(12\,\mu\mathrm{m})/S(25\,\mu\mathrm{m})$ and large $S(60\,\mu\mathrm{m})/S(100\,\mu\mathrm{m})$]. Furthermore we discuss in quantity the mentioned suggestion that there are two sizes of dust particle present and explain why the IR colour suggests this as follows. Using the Table 2 the relationships between the $\log L(\mathrm{IR})$ and $S(60)/S(100)$, and between the $\log L(\mathrm{IR})$ and $S(12)/S(25)$ are obtained, respectively. We find the $\log L(\mathrm{IR})$ is anticorrelated with $S(60)/S(100)$, and the $\log L(\mathrm{IR})$ is correlated with $S(12)/S(25)$. With least square fit the correlation coefficient in the anticorrelation is -0.73 with confidence level of greater than 95 percent, and the correlation coefficient in the correlation is 0.54 with confidence level of greater than 95 percent. Thus, from linear fits $(y = ax + b)$ to the anticorrelation and correlation of the sources investigated in the OH megamaser we obtain

$$S(60)/S(100) = -3.70[\log L(\mathrm{IR}) - 10] + 6.56\,,$$

for the anticorrelation,

$$S(12)/S(25) = 3.23[\log L(\mathrm{IR}) - 10] - 4.52\,,$$

for correlation.

Using the above equations the relationship between $S(60)/S(100)$ and $S(12)/S(25)$ is

$$S(60)/S(100) = -1.15[S(12)/S(25)] + 1.36\,.$$

We try to find the scale of suitable parameters of the dust particle using the relationships of $S(12)/S(25)$ and $S(60)/S(100)$. Assuming the dust particle as an ideal black-body sphere, r represents its radius, and the out-surface area is $2\pi r^2$ for every dust particle. Also assuming the source as a sphere with radius R, n_g is the density of dust particle in the surface area of the sphere, and T_g is the temperature of the dust particle. Thus we obtain

$$L(\mathrm{IR}) = 4\pi \mathrm{R}^2 \mathrm{n_g} 2\pi \mathrm{r}^2 \sigma \mathrm{T_g^4}\,,$$

where σ is the Stephanian-Boltzmann constant. Therefore

$$S(60)/S(100) = -3.70\log(R^2 n_g r^2 \sigma T_g^4) + 36.54\,, \tag{1}$$

$$S(12)/S(25) = 3.23\log(R^2 n_g r^2 \sigma T_g^4) - 30.683\,. \tag{2}$$

When

$$S(60)/S(100) = S(12)/S(25), \quad \log(R^2 n_g r^2 \sigma T_g^4) = 9.7\,.$$

Meantime

$$S(60)/S(100) > 0, \quad \mathrm{from}(1)$$

$$\log(R^2 n_g r^2 \sigma T_g^4) < 9.9\,.$$

And

$$S(12)/S(25) > 0, \quad \mathrm{from}(2)$$

$$\log(R^2 n_g r^2 \sigma T_g^4) > 9.5\,.$$

Thus at the situation of smaller dust particle, r is smaller, when

$$9.5 < \log(R^2 n_g r^2 \sigma T_g^4) \le 9.7\,,$$

$$S(12)/S(25) \le S(60)/S(100)\,.$$

At the situation of larger dust particle, r is larger, when

$$9.7 \le \log(R^2 n_g r^2 \sigma T_g^4) < 9.9\,,$$

$$S(60)/S(100) \le S(12)/S(25)\,.$$

4 Conclusion

We have studied the relationship between L(OH) and L(IR) of the complete sample of 66 OH megamaser sources, which have the data of L(OH) and L(IR). Accounting for Malmquist bias the relationship $L(\mathrm{OH}) \sim \mathrm{L(IR)}^{1.41}$ has been obtained.

The IR-properties of the host IRAS sources with the OH megamasers have also been studied in this paper. The most striking features are anticorrelation of $S(60\,\mu\mathrm{m})/S(100\,\mu\mathrm{m})$ vs. $S(12\,\mu\mathrm{m})/S(25\,\mu\mathrm{m})$, and anticorrelation of $\log L(\mathrm{IR})$ vs. $S(60\,\mu\mathrm{m})/S(100\,\mu\mathrm{m})$, and correlation of $\log L(\mathrm{IR})$ vs. $S(12\,\mu\mathrm{m})/S(25\,\mu\mathrm{m})$, respectively. The anticorrelation and the correlation between the flux density ratios and $\log L(\mathrm{IR})$ can be explained by the coexistence of large and very small dust particles. The very small dust which are heated transiently by single photon absorption are believed to be responsible for the bulk of the $25\,\mu$m radiation. In case the photon energy density of the host galaxy is small, this implies small $S(12\,\mu\mathrm{m})/S(25\,\mu\mathrm{m})$ and large $S(60\,\mu\mathrm{m})/S(100\,\mu\mathrm{m})$. However, when the photon energy density becomes larger, the infrared spectrum will peak at wavelengths $\leq 100\,\mu$m thus enhancing the emission at 100μ. As a consequence large S(12μm)/S(25μm) and small (60μm)/S(100μm) color temperatures are observed. This effect might be enhanced by the destruction of small dust particle due to shock waves occurring near the nuclear regions.

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References

Baan W.A., ApJ, 1989, 338,804
Baan W.A., Salzer J.J., LeWinter R.D., ApJ, 1998, 509, 633
Baan W.A., Wood P., Haschick A.D., ApJ, 1982, 260, L49
Paturel G., in Star Forrmation in Galaxies, ed C.J. Lonsdale, Persson (Washington:NASA), 1987, p.597
Darling J., Giovanelli R., AJ, 2000, 119: 3003
Darling J., Giovanelli R., AJ, 2001, 121: 1278
Henkel C., Wilson T.L., A&A, 1990, 229: 431
Kandalian R.A., Astrophysics, 1996, 39: 237
Nguyen-Q-Rieu, Mebold U., Winnberg A., et al. A&A, 1976, 52: 467
Phillips C.J., Norris R.P., Ellingsen S.P., et al. MNRAS, 1998, 294: 265
Staveley-Smith L., Norris R.P., Chapman J.M., et al. MNRAS, 1992, 258: 725
Whiteoak J.B., Gardner F.F., Ap.Letters, 1973, 15: 211
Yu Zhi-yao. Astronomy Progress, 1991, 9: 289