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Long-term variability of H_2O masers in YSOs

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Abstract. A sample of 14 water maser sources associated with young stellar objects (YSOs) has been monitored over 13 years with the Medicina 32-m antenna. The YSOs have been selected with bolometric luminosities from 20 $L_\odot$ to 2×10^6 $L_\odot$ with the aim of investigating the relationship between H_2O maser variability and stellar mass. The results are presented in various graphical forms which allow to follow the variation of the different spectral components. In particular, four quantities have been considered in our analysis: the intensity of the maser lines as a function of time and velocity; the flux integrated over the observed velocity range as a function of time; the maximum flux ever observed at each velocity; and the frequency of occurrence of the maser emission at any given velocity.

1. Introduction

It is well known that the 6_{16}-5_{23} rotational transition of water at 22.2 GHz is masing in YSOs. An interesting feature of this line is its extreme time variability. In spite of the observational and theoretical efforts performed in the past, a satisfactory explanation remains to be found for the origin of the variability. Although single features can undergo strong changes on intervals as short as one day, most variations occur on time scales of a few weeks.

With the purpose of shedding light on the nature of this phenomenon, we have monitored a sample of 14 H_2O maser sources in star forming regions over a long period of time ($\sim$13 years) with a sampling interval of $\sim 1-2$ months. The sources have been selected from the Arcetri H_2O maser catalog (Comoretto et al. 1990; Brand et al. 1994; Valdettaro et al. 2001), and contain YSOs spanning five orders of magnitude in bolometric luminosity, from 20 $L_\odot$ to 2×10^6 $L_\odot$. Our goal is to investigate the relationship between the characteristics of the YSOs and the observed water maser variability.

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2. Observations

The observations were performed with the Medicina 32-m antenna from 1987 until the end of 1999, in many sessions separated by at least ~1 month. The telescope HPBW at 22.2 GHz is 1.9′. The pointing accuracy is better than ~ 25″. We estimate an uncertainty of ~ 30% on the absolute flux scale. Typical integrations of 5 min on-source were performed resulting in a 1σ RMS noise of ~0.5 Jy. In a few cases longer integration times have been used. The list of monitored sources and the main observational and derived quantities are listed in Table 1. $V_{\rm cl}$ is the cloud velocity relative to the LSR, $V_{\rm up}$ ($\Delta V_{\rm up}$) is the mean velocity (and its dispersion) weighted by the peak flux, $L_{\rm H_2O}$ is the maser luminosity computed if all the velocity components present in the spectra over the whole observing period would emit at their maximum and at the same time. Finally, $L_{\rm FIR}$ is the integrated far-infrared luminosity.

#	Source Name	d (kpc)	$V_{\rm cl}$ (km s^{-1})	$V_{\rm up}$ (km s^{-1})	$\Delta V_{\rm up}$ (km s^{-1})	$L_{\rm H_2O}$ ($L_\odot$)	$L_{\rm FIR}$ ($L_\odot$)
1	Sh 2-184	2.2	−30.8	−32.2	12.1	2.0 10^{-4}	7.9 10^3
2	L1455 IRS1	0.35	4.8	4.1	4.1	9.5 10^{-7}	2.0 10^1
3	NGC 2071	0.72	9.5	12.1	10.4	3.1 10^{-4}	1.4 10^3
4	Mon R2 IRS3	0.8	10.5	10.5	9.3	2.3 10^{-5}	3.2 10^4
5	Sh 2-269 IRS2	3.8	18.2	17.5	7.9	2.6 10^{-4}	6.0 10^4
6	W43 Main3	7.3	97.0	101.2	28.5	7.7 10^{-3}	1.8 10^6
7	G32.74−0.08	2.6	38.2	34.1	7.1	1.7 10^{-5}	5.3 10^3
8	G34.26+0.15	3.9	57.8	54.2	25.8	2.8 10^{-3}	7.5 10^5
9	G35.20−0.74	1.8	34.0	34.2	8.0	7.3 10^{-5}	1.4 10^4
10	G59.78+0.06	1.3	22.3	26.0	10.4	6.1 10^{-5}	5.3 10^3
11	Sh 2-128(H_2O)	6.5	−71.0	−72.7	13.3	4.0 10^{-3}	8.9 10^4
12	NGC7129/FIRS2	1.0	−10.1	−4.6	12.6	6.7 10^{-5}	4.3 10^2
13	L1204-A	0.9	−7.1	−8.5	20.0	2.4 10^{-5}	2.6 10^4
14	L1204-G	0.9	−10.8	−18.1	14.3	2.2 10^{-5}	5.8 10^2

Table 1. The H_2O maser sample

3. Results

As shown in fiigure 1, the H_2O maser luminosity correlates very well with the bolometric luminosity of the YSO. A power-law fit gives the relation: $L_{\rm H_2O} = 2.6 \times 10^{-7} L_{\rm FIR}$.

The maser LSR velocity, $V_{\rm up}$, differs by less than 10 km s^{-1} from the corresponding molecular cloud velocity, $V_{\rm cl}$. The velocity distribution of $V_{\rm up} - V_{\rm cl}$ has a smaller dispersion than that found using the peak velocity of the H_2O maser spectra taken at a single epoch. We also find that the velocity range of emission, $\Delta V_{\rm up}$, correlates with the YSO luminosity: the H_2O maser spectra of luminous YSOs display more high velocity features than low-luminosity objects.

Figure 2 shows that there is an anti-correlation between the YSO luminosity and the ratio between the maximum and the mean integrated flux. Such a ratio represents a way to express the variability of the integrated maser emission. Clearly, high-luminosity sources tend to be associated with less variable masers.

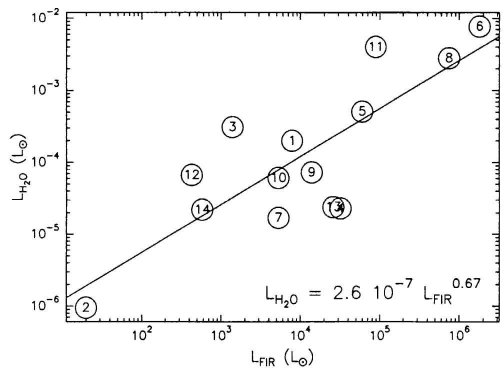

Figure 1. Plot of the H_2O maser luminosities versus the bolometric luminosities of the corresponding YSOs. The line is a least square fit to the data. The numbers correspond to those given in column 1 of table 1.

Note also that, although the flux density of individual features can vary by huge factors (several orders of magnitudes), the variation of the integrated emission is much more limited, reaching a factor of 10 only in one case (L1455 IRS1).

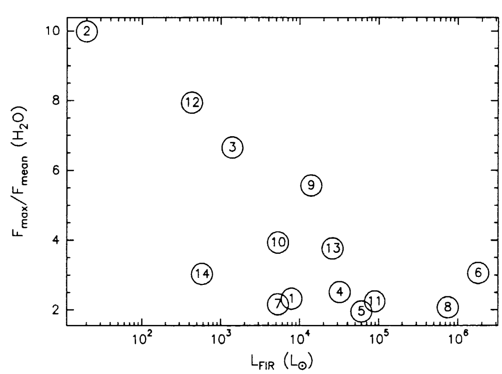

Figure 2. Plot of the ratio of the maximum and mean integrated H_2O flux as a function of the YSO luminosity.

A plot of the time-velocity-flux density represents a suitable way of displaying the global variability of the maser emission over the whole observing period. This diagram is particularly useful for recognizing the presence of velocity drifts, for separating steady components from bursts of short duration, and for studying the properties of the emission features as a function of velocity.

As an illustration, Figure 3 shows this diagram for four objects. For L1455 IRS1, the source with the lowest $L_{\rm FIR}$, we see three distinct masing epochs separated by two and six years each during which the maser has been quiescent. For L1204-G we note that the feature at $V_{\rm LSR} \sim -20$ km s^{-1} is steadily visible for the 13 years of observations and undergoes a small, but noticeable drift. Similar drifts, although of shorter duration, are visible at other velocities. Small drifts are also displayed in the case of L1204-A, a source brigther than L1204-G

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in the same star forming region. The case of W43 Main3, the brightest source of our sample, is much more complex. Emission is always present at many velocities and extends over an interval of $\sim$ 70 km s^{-1}. Several linear or arc-like structures, indicating systematic changes of the gas velocity, are clearly present.

4. Conclusions

The main finding of this study is that H_2O masers associated with more luminous YSOs are more powerful, less variable, and richer in terms of spectral features. Some spectral features are subject to non−random velocity changes, suggestive of the systematic motions of the maser environment, such as expansion driven by the associated molecular outflow or (less likely) rotation in circumstellar disks.

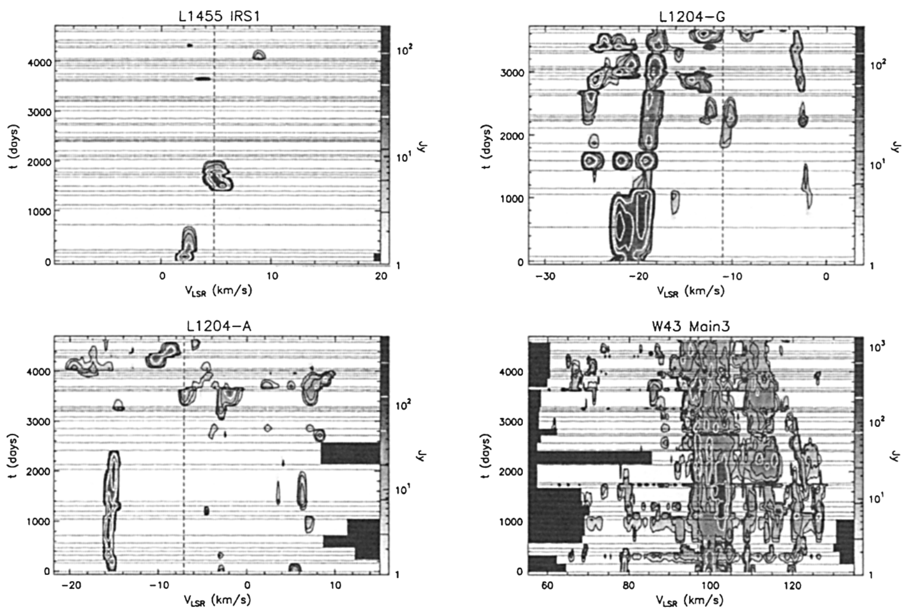

Figure 3. Examples of grey scale plot and contour map of the H_2O flux density versus velocity as a function of time. The vertical dashed line indicates the systemic velocity of the cloud, $V_{\rm cl}$.

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