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THREE NEW H_2O MASERS LOCATED NEAR HERBIG-HARO-LIKE NEBULOSITIES (Research Note)

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RESUMEN

Estudiamos 77 objetos tipo Herbig-Haro (Herbig-Haro-like o HHL) encontrados en Byurakan buscando emisión de maser del vapor de agua. Esta lista incluye los 37 objetos GGD reportados por Gyulbudaghian, Glushkov y Denisyuk (1978). Detectamos 11 máseres de los cuales 3 son nuevas fuentes. Estas fuentes son HHL5 (= G1-4). HHL50 (= GGD20), y HHL73 (= G2-11). La fuente HHL5 está asociada con la fuente infrarroja GL437. Hay una fuerte correlación en los objetos HHL entre la asociación con máseres de H_2O y con fuentes brillantes en el lejano infrarrojo.

ABSTRACT

We surveyed 77 Herbig-Haro-like (HHL) nebulosities found at Byurakan for water-vapor maser emission. This list includes the 37 GGD objects reported by Gyulbudaghian, Glushkov and Denisyuk (1978). We detected 11 masers, of which 3 are new sources. These new sources are HHL5 (= G1-4), HHL50 (= GGD20) and HHL73 (= G2-11). HHL5 is associated with the infrared source CRL437. There is a strong correlation in HHL objects between the association with H_2O masers and bright far-infrared sources.

Key Words: **HERBIG-HARO OBJECTS – MASERS**

I. INTRODUCTION

Herbig-Haro (HH) objects are known to be excellent tracers of star formation activity. In an attempt to increase the number of known HH objects, one of us (ALG) has systematically inspected the Palomar Sky Survey prints for nebulosities that morphologically resemble HH objects. Detailed spectroscopic studies (Gyulbudaghian *et al.* 1978; Hartigan and Lada 1985; Cohen and Fuller 1985; Strom *et al.* 1986) have shown that only a fraction of these Herbig-Haro-like (HHL) objects are *bona fide* HH objects. Another fraction of the objects is constituted by reflection nebulae and by stars associated with nebulosity. In any case, the HHL objects are good indicators of recent star formation, as shown by the study of Rodríguez *et al.* (1980).

In this research note we report the results of a survey for H_2O maser emission in a list of 77 HHL objects. We also discuss the correlation between H_2O masers and bright far-infrared sources in the vicinity of HHL objects.

II. OBSERVATIONS

The observations were made in 1982 October and November, and 1985 May using the 37-m radio telescope of the Haystack Observatory[1]. In 1982 we surveyed the list of twenty-one G1 objects (Gyulbudaghian 1983), while in 1985 we surveyed the complete list of seventy-seven HHL objects (Table 1). At the frequency of the 6_{16}-5_{23} transition of H_2O ($\nu = 22.235080$ GHz), the beam size is 1'.5 and the aperture efficiency is about 0.23 at an elevation of 45°. The receiver was a cooled K-band maser and the spectrometer a 512-channel digital au-

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tocorrelator. The effective bandwidth was 13.3 MHz ($\sim$ 179 km s^{-1}) and the spectral resolution was 0.88 km s^{-1} after Hanning weighting. The Herbig-Haro-like (HHL) objects found at Byurakan were observed using position switching in most sources and frequency switching in a few of them. A list of the HHL objects is given in Table 1. A seven-point map (Rodríguez *et al.* 1978) was made centered on each HHL object. We detected maser emission in 11 objects of the list. Eight of them were detected in our previous surveys (Rodríguez *et al.* 1978; 1980) of a subset of the HHL object list, namely the so-called GGD objects (Gyulbudaghian, Glushkov and Denisyuk 1978). The three new detections are HHL5 (= G1-4), HHL50 (= GGD20), and HHL73 (= G2-11). These new masers do not appear in the catalogs of Dinger and Dickinson (1980) and Braz and Epchtein (1983). Spectra of these masers are shown in Figures 1, 2 and 3, and their parameters are given in Table 2. According to the

TABLE 1

LIST OF HERBIG-HARO-LIKE OBJECTS FOUND AT BYURAKAN

HHL	α(1950)	δ(1950)	Other Name[a]	H_2O Maser Associated?	Ref. Detection[b]	HHL	α(1950)	δ(1950)	Other Name[a]	H_2O Maser Associated?	Ref. Detection[b]
1	00^h17^m8	+ 61°41°	G1-1	No		41	06 10.3	− 06 14	GGD16	Yes	3
2	00 18.0	+ 61 40	GGD1	No		42	06 10.4	− 06 12	GGD17	Yes	3
3	00 33.9	+ 63 12	G1-2	No		43	06 24.9	− 10 08	G3-1	No	
4	02 55.9	+ 17 04	G1-3	No		44	06 31.9	+ 04 15	GGD18	No	
5	03 03.5	+ 58 20	G1-4	Yes	1	45	06 36.9	+ 01 35	GGD19	No	
6	03 13.4	+ 59 59	...	No		46	06 56.9	− 03 56	G3-2	No	
7	03 25.7	+ 30 58	GGD2	No		47	06 57.1	− 04 42	G3-3	No	
8	03 25.8	+ 30 54	GGD3	No		48	06 57.2	−04 46	G3-4	No	
9	03 33.3	+ 37 05	G1-5	No		49	07 07.0	− 10 45	G2-7	No	
10	03 44.5	+ 32 50	G1-6	No		50	07 22.6	− 24 28	GGD20	Yes	1
11	03 48.5	+ 38 44	G1-7	No		51	07 22.7	− 24 23	GGD21	Yes	1
12	03 57.2	+ 36 03	G1-8	No		52	07 22.8	− 24 24	GGD22	Yes	1
13	04 07.3	+ 38 00	G1-9	No		53	07 23.2	− 24 22	GGD23	Yes	1
14	04 19.0	+ 26 50	G2-1	No		54	16 22.2	− 09 30	G2-8	No	
15	04 23.7	+ 25 56	G1-10	No		55	16 22.5	− 09 38	G2-9	No	
16	04 24.0	+ 23 53	G1-11	No		56	16 31.4	− 15 41	GGD24	No	
17	04 59.1	− 08 57	G1-12	No		57	17 17.0	− 35 51	GGD25	Yes	2
18	05 17.3	− 05 56	G1-13	No		58	17 27.8	− 20 08	GGD26	No	
19	05 25.1	+ 11 29	G2-2	No		59	17 55.5	− 26 07	G1-19	No	
20	05 26.0	+ 11 51	G2-3	No		60	18 16.1	− 20 49	GGD27	Yes	2
21	05 26.5	+ 11 26	G2-4	No		61	18 16.3	− 20 48	GGD28	Yes	2
22	05 29.1	+ 12 25	G2-5	No		62	18 27.5	+ 01 14	GGD29	Yes	2
23	05 29.6	+ 12 49	G1-14	No		63	18 49.1	+ 00 26	GGD30	No	
24	05 32.8	+ 03 55	G2-6	No		64	20 23.2	+ 39 01	GGD31	No	
25	05 35.6	+ 30 34	G1-15	No		65	20 52.5	+ 66 59	G2-10	No	
26	05 37.4	+ 23 51	GGD4	Yes	2	66	21 00.4	+ 78 11	G1-20	No	
27	05 37.5	+ 35 37	GGD5	Yes	3	67	21 04.2	+ 66 35	G3-5	No	
28	05 37.6	+ 35 42	GGD6	Yes	3	68	21 41.2	+ 65 51	GGD32	Yes	3
29	05 38.4	− 08 09	GGD7	No		69	21 41.9	+ 65 58	GGD33	Yes	3
30	05 38.7	− 08 06	G1-16	No		70	21 42.3	+ 65 55	GGD34	Yes	3
31	05 44.0	+ 30 34	G1-17	No		71	21 42.4	+ 58 00	...	No	
32	05 48.2	+ 03 07	GGD8	No		72	21 42.5	+ 65 55	GGD35	Yes	3
33	05 53.0	+ 03 23	GGD9	No		73	21 43.3	+ 47 19	G2-11	Yes	1
34	05 59.8	− 09 07	GGD10	No		74	21 56.9	+ 58 42	GGD36	No	
35	06 05.6	− 06 25	G1-18	No		75	22 05.1	+ 58 48	G1-21	No	
36	06 06.2	− 06 18	GGD11	No		76	22 26.1	+ 63 04	G2-12	No	
37	06 08.3	− 06 12	GGD12	Yes	2	77	22 54.3	+ 61 46	GGD37	Yes	3
38	06 08.4	− 06 12	GGD13	Yes	2						
39	06 08.4	− 06 11	GGD14	Yes	2						
40	06 08.4	− 06 10	GGD15	Yes	2						

a. G1 = Gyulbudaghian 1983; G2 = Gyulbudaghian 1984*a*; G3 = Gyulbudaghian 1984*b*; GGD = Gyulbudaghian, Glushkov and Denisyuk 1978.

b. 1 = This paper; 2 = Rodríguez *et al.* 1978; 3 = Rodríguez *et al.* 1980.

TABLE 2

NEW H_2O MASERS ASSOCIATED WITH HERBIG-HARO-LIKE OBJECTS

HHL	α(1950)	δ(1950)	S_L (Jy)	V_{LSR} (km s^{-1})	V_{CO} (km s^{-1})	Distance (kpc)	$L(H_2O)$ ($L_\odot$)
5	$03^h03^m34.2$	+ 58° 19′13″	2,3,3	−28, −39, −49	− 40	1.5	4×10^{-7}
50	07 22 33.4	− 24 28 58	12	24	+ 19	1.4	6×10^{-7}
73	21 43 14.0	+ 47 19 15	16	− 2	+ 4	0.9	2×10^{-7}

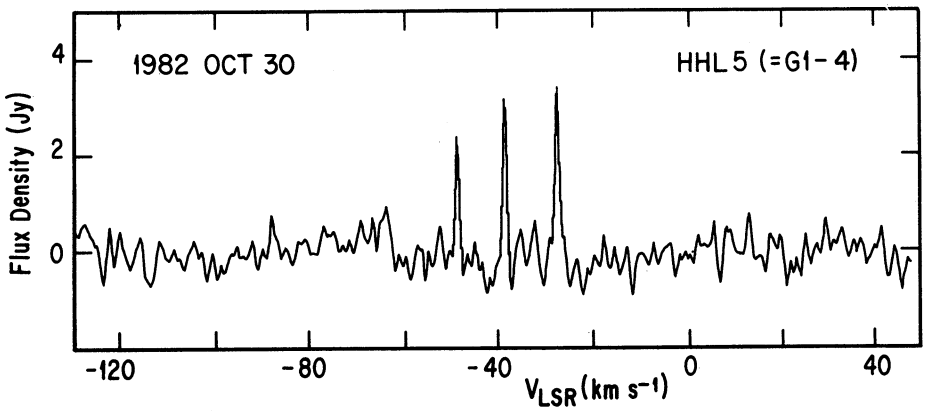

Fig. 1. Spectrum of the water maser associated with HHL5 (= G1-4). The velocity resolution is 1.8 km s^{-1}. This source is associated with CRL437.

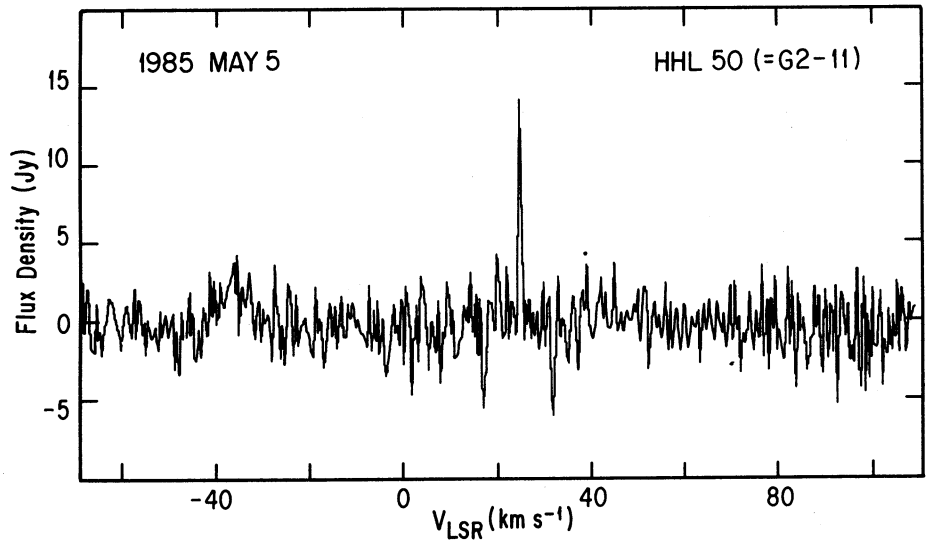

Fig. 2. Spectrum of the water maser associated with HHL50 (G2-11). The velocity resolution is 0.88 km s^{-1}. This spectrum was obtained with the frequency-switching technique. This technique produces the two apparent "absorption" features symmetrically displaced with respect to the emission line.

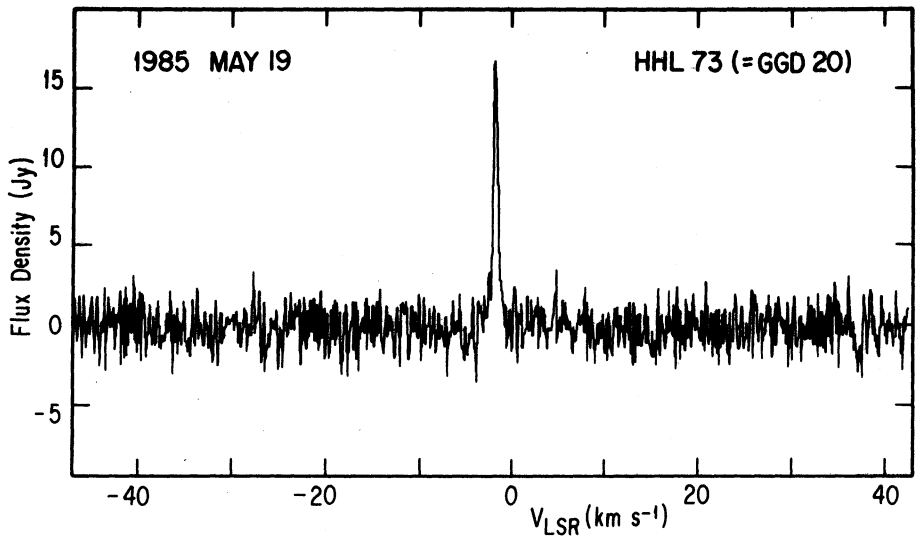

Fig. 3. Spectrum of the water maser associated with HHL73 (GGD20). The velocity resolution is 0.22 km s^{-1}.

classification of Genzel and Downes (1977), the maser associated with HHL5 is a triple line source (T), while those associated with HHL50 and HHL73 are single line sources (S).

III. COMMENTS ON THE DETECTED SOURCES

a) *HHL5*

This nebulosity is closely associated with the infrared source CRL437 (Kleinmann *et al.* 1977). There is a molecular cloud centered on CRL437, that has a velocity gradient suggestive of rotation (Schneps *et al.* 1978). Arquilla and Goldsmith (1984) propose that the cloud is not rotating significantly and that the velocity gradient is due to the presence of a bipolar outflow. The CO velocity and distance given in Table 2 are taken from Schneps *et al.* (1977).

b) *HHL50*

There is very little information on this source. From the data of Rodríguez *et al.* (1980) we derived the CO velocity and kinematic distance given in Table 2.

c) *HHL73*

This HHL object is located at about 20′ to the west of the FU Ori star Elias 1-12 (Elias 1978). The CO velocity given in Table 2 was measured by Levreault (1985) at the position of Elias 1-12 and the distance is that given by Elias (1978) for the star.

IV. DISCUSSION AND CONCLUSIONS

The 77 HHL nebulosities observed by us can be divided into two types of objects for observational convenience: 1) singles; objects that do not have neighbors within a circle of 5′ in diameter and, 2) multiples; objects in groups of two or more closer than 5′. The 77 objects form 60 systems: 49 singles, 8 doubles (HHL 1-2, 7-8, 15-16, 27-28, 29-30, 41-42, 47-48, and 60-61), and 3 quadruples (HHL 37-38-39-40, 50-51-52-53, and 68-69-70-72). Of these 60 systems, 12 (20%) are associated with H_2O maser emission.

We have tried to establish a correlation between the presence of H_2O maser emission and that of bright far-infrared sources. Using the IRAS Point Source Catalog (1985) we searched for sources with flux density larger than 100 Jy at 60 or 100 μm that were located within 3′ of an HHL object. We found 16 of these bright far-infrared sources. In one case (HHL 27-28) we found two associated IRAS sources (IRAS 05375+ 3536 and

TABLE 3

BRIGTH FAR-INFRARED SOURCES ASSOCIATED WITH HHL OBJECTS

IRAS	HHL	H_2O?
00338 + 6312	3	No
03035 + 5819	5	Yes
05375 + 3540	27-28[a]	Yes
05439 + 3035	31	No
06084 – 0611	37-38-39-40	Yes
06103 – 0612	41-42	Yes
06249 – 1007	43	No
06319 + 0415	44	No
06567 – 0355	46	No
07069 – 1045	49	No
17172 – 3548	57	Yes
17554 – 2606	59	No
18162 – 2048	60-61	Yes
18273 – 0113	62	Yes
22543 + 6145	77	Yes

a. HHL 27-28 is also associated with IRAS 05375 + 3540.

TABLE 4

CONTINGENCY TABLE FOR H_2O MASERS AND BRIGTH FAR-INFRARED SOURCES ASSOCIATED WITH HHL OBJECTS

	H_2O Maser	No H_2O Maser
Bright Far-IR Source	8	7
No Bright Far-IR Source	4	41

IRAS 05375+ 3540). We can then conclude that of the 60 HHL systems, 15 (25%) are associated with bright, far-infrared IRAS sources (Table 3). Of the 15 HHL systems associated with bright frar-infrared sources, 8 (53%) have associated H_2O maser emission (Table 4). Clearly, there is a strong correlation between the presence of H_2O maser emission and that of bright far-infrared sources. A chi-square test supports the correlation, since the probability of a random ocurrence is at the 0.1 percent level.

In summary, we have detected three new H_2O masers near HHL objects. One of these masers (HHL5) is associated with the infrared source CRL437. We also showed that there is a strong correlation between the presence of H_2O masers and bright far-infrared sources in the vicinity of HHL objects.

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