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A SURVEY OF DUST CLOUDS FOR OH EMISSION

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ABSTRACT

OH was detected in twenty out of seventy-nine interstellar dust clouds. Radial velocity is close to that of nearby hydrogen. The clouds at very low galactic latitude show the OH in absorption.

OH emission, suspected to be normal thermal emission, was previously observed in four interstellar dust clouds by Heiles (1968). Dust clouds are suspected to contain most of their hydrogen as H_2 or in solid form on grains. If H_2 predominates, there would be about 100 H_2 molecules cm^{-3}. In the four clouds previously reported, there were about 10^{-6} OH molecules cm^{-3}. With normal chemical abundances there would be a ratio of OH to O of about 10^{-5}.

We have performed a new survey for OH emission only at 1667 MHz in dust clouds in order to prepare a catalogue from a meaningful sample of clouds. One of us examined every print of the *Palomar Sky Atlas* for the presence of dust clouds, which seemed to be unusually dark. Among the clouds chosen were seventy-seven which were observed. Various practical reasons caused the integration times of the radio observations to vary over a range of 2–13 hours. The longer integration times fell onto clouds representing an unbiased sample of the original list. In addition, we observed a suspected protoplanetary system, R Mon, and a dust cloud identified only by its 10 magnitudes of visual extinction of VI Cyg No. 12.

The observations were made with the Hat Creek 85-foot radio telescope and 100-channel filter receiver. Channel widths and spacings of 2 kHz were used, giving a velocity range of ± 18 km sec^{-1} about the center channel. The system noise temperature was about 175° K.

Each object on the list was observed during sessions in October and December 1967. Objects which appeared to show OH were reobserved in February–March and May–June 1968. Most of the suspected objects with emission were confirmed. Table 1 gives the observational results and includes all clouds observed in this program and the previous one by Heiles (1968). We have named the clouds by the galactic coordinates of the apparent optical center, chosen by eye in the *Palomar Sky Atlas*. The 33′ antenna beam was centered at this position. The position of maximum OH brightness was not determined. Conservatively speaking, the peak antenna temperature in the line has an uncertainty of about 0.1° K and the velocity with respect to the local standard of rest has an uncertainty of about 0.5 km sec^{-1}.

The central velocity of the search observations was taken to be the central velocity of neutral hydrogen in that direction. Confirming observations were centered on the velocity of the suspected feature, and both values are given in Table 1. We also give the total number of hours of integration and the number of observing sessions on each object. An "H" indicates observations from the original paper by Heiles (1968), and a question mark indicates uncertain identification of the existence of a line.

Four obvious statistical relationships stand out for the clouds showing OH.

1. *Correlation with Gould's belt.*—Most of the clouds with OH lie in Gould's belt, simply because most dust clouds lie in Gould's belt, except for the cloud complex at 120° longitude.

2. *Low-latitude absorption.*—OH at low latitudes is usually in absorption. We have observed absorption near W31, W44, and W80. The OH absorption in the latter two objects has been confirmed by one of us with the NRAO 140-foot radio telescope and 100-channel autocorrelation receiver. The equation of transfer yielding the observed OH-line brightness temperature T_B is

$$T_B = (T_{\rm OH} - T_c)(1 - e^{-\tau}) ,$$

where $T_{\rm OH}$ is the OH excitation temperature, T_c the continuum brightness temperature behind the cloud, and τ the OH-line optical depth. For absorption we require $T_{\rm OH} < T_c$. The continuum brightness temperatures at 18-cm wavelength for the four clouds showing absorption, determined from Westerhout's (1958) survey, are G12.7−0.5, 6° K; G34.3−0.8, 6° K; G35.4+0.1, 9° K; G84.7−1.0, 6° K. These quite small temperatures are upper limits to $T_{\rm OH}$. The general nature of these results is confirmed by direct measurements of $T_{\rm OH}$ by Heiles (1969), who also treats the problem of $T_{\rm OH}$ theoretically.

The tendency toward absorption at low galactic latitudes, then, reflects the generally higher continuum background at low latitudes; we expect to see OH in absorption near the galactic plane and in emission far from the plane. At intermediate latitudes where the continuum temperature typically equals the excitation temperature, the line vanishes. This is apparent in Table 1; many clouds were observed between $b^{\rm II} = 2°$ and $b^{\rm II} = 6°$, but none showed OH lines.

3. *OH and H velocity correlation.*—The OH velocity is always within ±2 km sec^{-1} of the nearby 21-cm hydrogen velocity, as given by van Woerden, Takakubo, and Braes (1962) for intermediate latitudes and by van de Hulst, Müller, and Oort (1954) or by Westerhout (1966) for low latitudes.

The objects showing OH absorption are particularly interesting. We chose these clouds because of the presence of dust, without realizing the presence of nearby continuum sources. Comparison of the H I absorption spectrum of W44 with the OH absorption spectrum of G35.4+0.1, 0°.95 away, reveals that the H I absorption is centered at 12, 30, and 42 km sec^{-1} and the OH absorption at 13.4 and 28.9 km sec^{-1}. Goss (1968) observed OH absorption in W44 at 12, 25, and 43 km sec^{-1}, but he also found non-thermal OH emission at 13 and 43 km sec^{-1}. Goss and Robinson (1968) further observed emission at 43.4 and 46.3 km sec^{-1} but did not see anything at 13 km sec^{-1}. Our measurements did not reach velocities above 30 km sec^{-1}.

We believe that the non-thermal emission is associated with H II regions and that the thermal emission assumed in the main content of this Letter is associated with dust clouds. If that is true, only the 28.9 km sec^{-1} feature that we observed is associated with dust.

Another interesting case of absorption occurs with the "Gulf of Mexico" dust cloud, G84.7−1.0, which is 0°.36 away from Goss's (1968) measurement on the North America Nebula, W80. Goss used the same antenna we did, but he pointed it at the position of peak continuum brightness. There is a great deal of dust at Goss's central position, and our beam areas overlap. Our velocity is 3.6 km sec^{-1} higher than Goss's. This velocity difference occurs over a linear distance of 13 pc if the kinematic distance of W80 from Dieter (1967) is correct. On the other hand, G173.9−15.9 and G173.3−16.3, which are separated by 0°.72, have the same velocities within the measurement uncertainty. If the OH that we observe is really associated with the dust clouds, these appear to be the first measurements of dust-cloud velocities and velocity structures.

4. *Probability of OH occurrence.*—Most of the OH antenna temperatures that we observed were close to the sensitivity limit, so that longer integration times and/or lower system temperature would enable more to be detected. It is significant that no cloud was found with a much higher abundance of OH than in Heiles' first list.

Table 1

Galactic coord.	Right ascension (1950.0)	Declination (1950.0)	T_A (°K)	V_R (km/sec)	Central V_R (km/sec)	Integ. time (hours)	No. of ses- sions	Line width (kHz)	
G 0.5+11.4	$17^h01^m36^s$	$-22°06'$			+3.0	2.2	1		
1.9+16.6	16 47 17	-17 58			+3.0	3.7	1		
2.0+ 9.9	17 10 51	-21 47			+3.0	0.9	1		
3.1+ 9.9	17 13 11	-20 56			+3.0	7.7	2		
3.7+18.3	16 45 55	-15 31			+3.0	4.5	1		
4.2+18.1	16 47 51	-15 18			+3.0	4.4	1		
4.2+35.8	15 50 50	-04 26	0.3	+3.0	0.0	14.2	1	3	H
4.5+16.7	16 53 13	-15 55			+3.0	2.5	1		
4.9+19.6	16 44 28	-13 52			+3.0	4.7			
5.1+19.1	16 46 33	-14 03			+3.0	7.0	2		
6.4+20.6	16 44 32	-12 08			+3.0	2.2	1		
8.7+22.2	16 44 18	-09 29			+3.0	2.4	1		
12.7- 0.5	18 11 58	-18 11	-0.2	+5.5	+8.0	7.0	2	4	
21.6+ 3.8	18 14 18	-08 21			+8.0	7.2	2		
23.5+ 8.2	18 02 11	-04 32	0.4	+6.6	+12.0	1.8	1	12	
24.9+ 5.4	18 14 54	-04 42			+8.0	8.0	2		
25.7- 0.4	18 36 46	-06 41			+8.0	2.2	1		
26.5+ 8.0	18 08 34	-02 02			+12.0,+6.2	7.3	2		
27.0+ 3.5	18 25 31	-03 43	0.2	+6.0	+8.0	4.0	1	12	?
27.1+ 3.5	18 25 45	-03 34	0.2	+5.8	+8.0,+5.8	7.2	2	20	
27.3+ 4.3	18 23 07	-03 01	0.3	+8.0	+8.0,+7.3	8.0	2	12	?
28.4- 6.3	19 03 09	-06 53			+8.0	4.0	1		
28.4+ 3.2	18 29 04	-02 37			+8.0,+7.3	8.5	2		
34.4- 0.8	18 54 27	+00 50	-0.1	+13.0	+8.0,+11.6	9.0	2	13	?
35.4+ 0.1	18 53 07	+02 10	-0.4 -0.3	+28.9 +13.4	+8.0,+13.4	14.8	2	16 22	
44.9- 6.6	19 34 34	07 27			+12.0	5.2	1		
46.2- 1.3	19 18 26	11 04			+12.0	5.1	1		

Table 1 (continued)

Galactic coord.	Right ascension (1950.0)	Declination (1950.0)	T_A (°K)	V_R (km/sec)	Central V_R (km/sec)	Integ. time (hours)	No. of ses- sions	Line width (kHz)
G 47.4- 0.9	$19^h19^m02^s$	12°21'			+12.0	5.3	1	
48.4- 5.8	19 38 29	10 49			+12.0,+9.1	12.0	2	
49.2- 1.3	19 24 16	13 44			12.0	5.3	1	
50.1+ 2.7	19 11 33	16 25			12.0	4.5	1	
51.8+ 2.8	19 14 18	18 00			8.0	4.0	1	
57.2+ 3.6	19 22 00	23 04			+12.0	+11.3	2	
58.2+ 3.5	19 24 39	23 52			+12.0,+12.4	7.8	2	
83.1- 2.0	20 52 31	41 41			0.0	4.0	1	
84.7- 1.0	20 54 23	43 30	-0.5	+2.9	0.0,+2.9	9.4	2	14
88.6+ 0.7	21 01 01	50 02			0.0,-6.1	7.2	2	
90.4+ 2.4	21 44 16	47 22			0.0	5.3	1	
91.9+ 3.9	21 00 16	52 10			-2.0,-2.7	8.1	2	
93.6- 4.5	04 25 57	54 06			-5.0	5.3	1	
93.9+ 9.9	20 36 45	57 33			-7.0	5.3	1	
97.2+ 9.9	20 52 03	60 03			-7.0	5.2	1	
102.7+15.3	20 43 15	67 34			-7.0,+2.4	8.9	2	
103.7+13.9	21 01 27	67 31			-7.0,+2.4	11.6	2	
107.0+ 5.4	22 18 38	63 11			-10.0	2.9	1	
108.1+13.2	21 39 27	70 04			-7.0	7.6	2	
109.7+ 2.6	22 51 40	62 08			-10.0,-14.3	11.6	2	
110.0- 1.1	23 05 35	58 51			-10.0	2.0	1	
113.6+17.2	21 59 36	76 38			-7.0,-4.1	7.6	2	
114.5+14.6	22 27 55	74 58	0.5	-4.0	-8.0	5.3	1	4 H
127.7+14.0	02 04 30	75 54	0.1	+3.0	-7.0,+3.0	15.7	3	12
150.4+ 3.9	04 20 27	54 52			-5.0	3.6	1	
159.7-19.6	03 33 19	31 03	0.1	+6.7	+4.0,+6.5	17.0	3	14
168.2-16.3	04 11 08	28 09			+5.0	5.3	1	
168.7-15.5	04 15 27	28 18	0.3	+7.2	+5.0,+7.2	9.8	2	10

Table 1 (continued)

Galactic coord.	Right ascension (1950.0)	Declination (1950.0)	T_A (°K)	V_R (km/sec)	Central V_R (km/sec)	Integ. time (hours)	No. of sessions	Line width (kHz)	
G 171.4-10.6	$04^h39^m58^s$	29°36'	0.1	+5.8	0.0,+5.8	11.6	2	12	
172.4- 8.0	04 52 13	30 32			-7.0,-11.2	8.0	2		
173.0- 5.5	05 03 00	31 37			0.0	16.8	2		
173.3-16.3	04 26 07	24 32	0.2	+6.4	+5.0,+6.4	12.0	2	8	
173.9-15.9	04 28 59	24 23	0.2	+5.7	+5.0,+5.7	12.5	2	8	
174.6-13.7	04 38 30	25 18	0.8	+6.1	+10.0	4.9	1	12	H
177.8-20.1	04 25 30	18 47			+4.0	5.7	1		
177.9- 9.7	05 00 56	25 10			-7.0	4.0	1		
178.8-20.1	04 28 12	18 06			+4.0,+6.9	12.0	2		
178.9- 6.7	05 14 26	26 07	0.2	+7.2	0.0,+7.2	7.1	2	10	
191.5- 0.8	06 05 01	18 34			+12.0	5.3	1		
195.2-17.1	05 15 16	07 07			+8.0	5.3	1		
201.5+ 0.6	06 29 50	10 32	0.2	+5.3	+10.0,+5.3	21.3	3	20	
203.3-11.2	05 51 12	03 19	0.2	+10.0	+10.0	24.2	3	6	
214.5-19.9	05 40 15	-10 14	0.2	+2.6	+8.0,+2.6	23.5	3	16	
224.4- 2.4	07 01 40	-11 14			+15.0	5.3	1		
237.7-29.0	05 35 49	-33 12			+8.0	4.0	1		
352.9+16.7	16 23 35	-24 30	0.4	+3.0	+3.0	4.9	1	8	
353.4+16.9	16 24 15	-24 04	0.5	+3.7	0.0	11.5	1	8	H
353.5+16.7	16 25 07	-24 06			+3.0	4.9	1		
354.0+15.6	16 30 20	-24 27			+3.0	5.4	1		
354.4+16.2	16 29 22	-23 47			+3.0	2.1	1		
355.3+14.7	16 37 11	-24 06			+3.0	2.8	1		
355.6+20.6	16 18 17	-20 03			0.0	2.8	1		
356.2+20.7	16 19 27	-19 33			0.0	3.8	1		
358.5+15.4	16 42 55	-21 14			+3.0	1.9	1		
R Mon	06 37 18	+08 48			10.0	1.6	1		
VI Cyg #12	21 30 53	41 05			-5.0	2.7	1		

Finally, it appears that there is an absorption core 2 kHz wide in some of the absorption lines. This is particularly apparent in the 13 km sec^{-1} component of G35.4+0.1, where it appears both in Hat Creek and NRAO observations. A definite statement on these cores awaits further observations.

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