

6-CENTIMETER FORMALDEHYDE ABSORPTION AND EMISSION IN THE ORION NEBULA

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ABSTRACT

Weak 6-cm H_2CO absorption has been found over much of the Orion Nebula, and is attributed to "anomalous" absorption of the universal microwave radiation by H_2CO behind the H II continuum source. In the Kleinmann-Low infrared nebula the line is self-reversed, with a core of about 0.1°K that is probably emission from the H_2CO observed there at 2 mm. These observations are interpreted as indicating that neutral-particle collisions suppress the pumping mechanism responsible for anomalous absorption.

The 6-cm (4830 MHz) line of H_2CO has been detected in the Orion Nebula, the most notable example of an intense H II region where it was not found by Zuckerman *et al.* (1970) in their 6-cm survey. Our search was motivated by the discovery of 2-mm H_2CO emission from the direction of the Kleinmann-Low (1967) infrared nebula (Kutner *et al.* 1971; Thaddeus *et al.* 1971 [accompanying Letter], hereafter called Papers I and II), from which it could be inferred that a 6-cm line of the order of 0.1°K should exist, and that because of the extremely high density in the infrared nebula, its detection might shed light on the role of collisions in the anomalous absorption process (Palmer *et al.* 1969; Townes and Cheung 1969).

Observations were made with the 140-foot telescope of the National Radio Astronomy Observatory¹ equipped with a cooled 6-cm parametric amplifier and 384-channel autocorrelator; the system noise temperature was typically 85°K , and the antenna was illuminated with a linear feed whose E -plane was north-south. Data were obtained at a spectral resolution of either 3.94 kHz (0.24 km s^{-1}) or 1.94 kHz (0.12 km s^{-1}), and were subsequently filtered over three channels. Some observations were made with frequency switching of the first local oscillator, others were taken in the "total power" mode.

The observations of the Orion Nebula are summarized in Figure 1 and Table 1. Column (1) in Table 1 gives the position shown in Figure 1; column (4) is the line intensity (continuum minus line peak) in units of brightness temperature; column (5) is the mean Doppler velocity of the line in the local standard of rest (LSR) based on the measurement by Tucker, Tomasevich, and Thaddeus (1970) of the 6-cm rest frequency; column (6) is the full line width at half-intensity; and column (7) is the continuum brightness temperature, either taken from Mezger and Henderson's (1967) 6-cm map of Ori A or calculated from 8-GHz continuum temperatures obtained by Gordon and Meeks (1968; Meeks 1971).

As Figure 1 shows, 6-cm absorption is found over much of the Orion Nebula at an intensity of $0.1^\circ\text{--}0.5^\circ\text{K}$. Position 17 centers on the Kleinmann-Low infrared nebula and the small ($\sim 3' \times 5'$) source of 2-mm H_2CO emission discussed in Paper II; it also

¹ Operated by Associated Universities, Inc., under contract to the National Science Foundation.

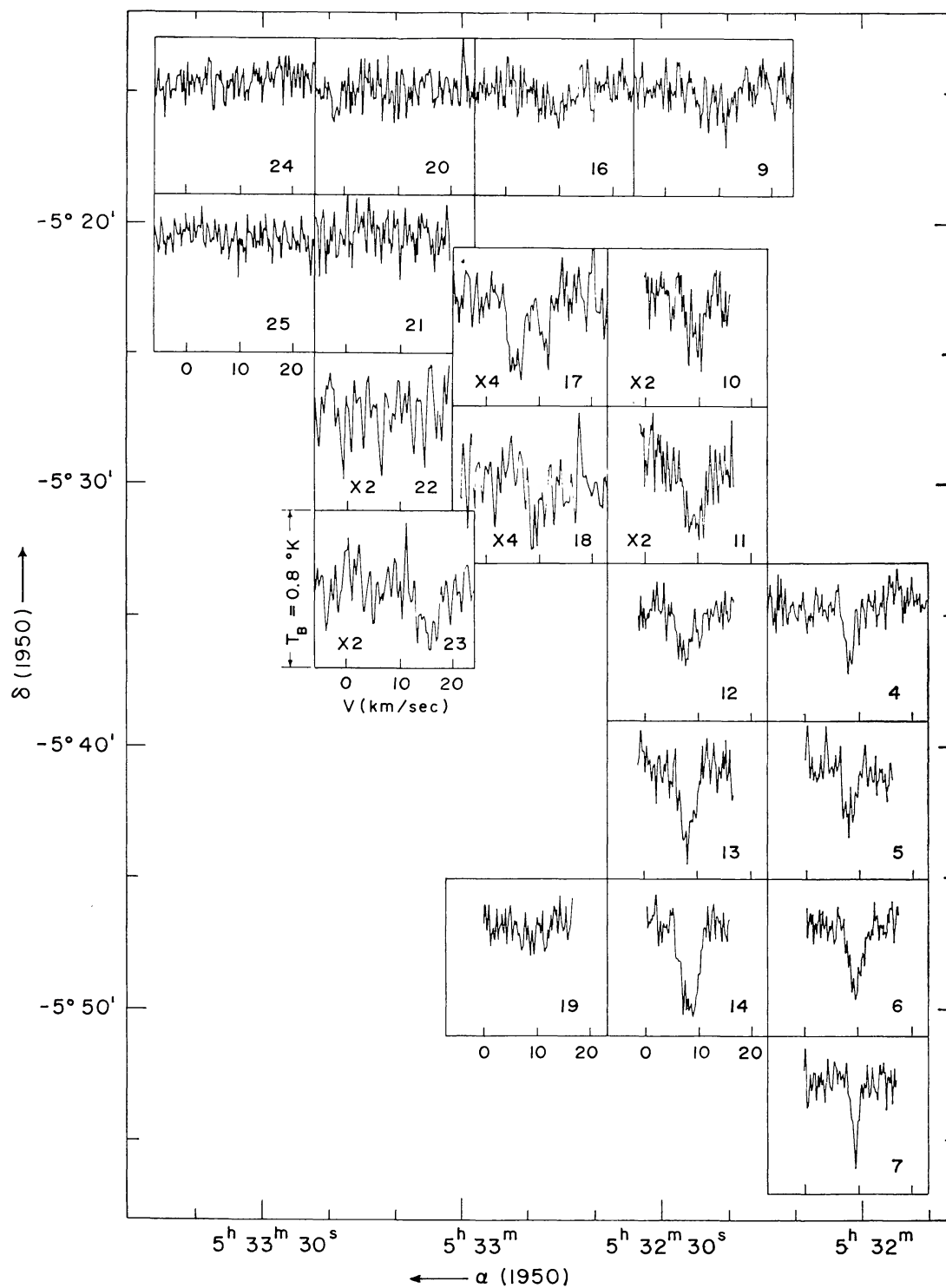


FIG. 1.—Map of 6-cm line profiles. The center of each square box is the direction of observation, and each box is approximately the size of the antenna beamwidth. The full vertical scale of the spectra is 0.8°K in T_B , unless indicated by X2 or X4, where it is respectively 0.4° and 0.2°K . The three horizontal scale marks in all cases indicate LSR radial velocities of 0, 10, and 20 km s^{-1} .

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TABLE 1
SUMMARY OF OBSERVATIONS

Position Number (1)	α (1950) (2)	δ (1950) (3)	T_L ($^{\circ}$ K) (4)	v_{LSR} (km s $^{-1}$) (5)	Δv (km s $^{-1}$) (6)	T_c ($^{\circ}$ K) (7)
1.....	5 ^h 31 ^m 36. ^s 0	-5 $^{\circ}$ 48'00"	<0.15	...	...	< 0.41*
2.....	5 31 36.0	-5 54 00	<0.15	...	...	< 0.41*
3.....	5 31 36.0	-6 00 00	$\sim$ 0.1(?)	9	...	< 0.41*
4.....	5 32 00.0	-5 36 00	0.33	8.5	3	< 2.4
5.....	5 32 00.0	-5 42 00	0.35	8	3	< 0.41*
6.....	5 32 00.0	-5 48 00	0.36	9	3	< 0.41*
7.....	5 32 00.0	-5 54 00	0.50	9.5	1.5	< 0.41*
8.....	5 32 00.0	-6 00 00	$\sim$ 0.1	9.5	2	< 0.41*
9.....	5 32 22.0	-5 16 00	0.1	9	7	< 2.4
10.....	5 32 24.0	-5 24 00	0.16	9.5	6	30
11.....	5 32 24.0	-5 30 00	0.18	9	5	10
12.....	5 32 24.0	-5 36 00	0.25	8.5	5	< 2.4
13.....	5 32 24.0	-5 42 00	0.48	8	4	< 0.41*
14.....	5 32 24.0	-5 48 00	0.50	8	4	< 0.41*
15.....	5 32 34.0	-5 12 00	<0.2	...	...	< 2.4
16.....	5 32 46.0	-5 16 00	0.15	9	6	3.5
17.....	5 32 46.7	-5 23 56	$\sim$ 0.1—See text	...	...	87
18.....	5 32 48.0	-5 30 00	$\sim$ 0.05	9	$\sim$ 4	25
19.....	5 32 48.0	-5 48 00	$\sim$ 0.1	8.5	6	< 0.41*
20.....	5 33 10.0	-5 16 00	0.15	9	...	2.5
21.....	5 33 10.0	-5 22 00	<0.2	...	...	6
22.....	5 33 10.0	-5 28 00	<0.15	...	...	6
23.....	5 33 10.0	-5 34 00	0.10	16	5	< 2.4
24.....	5 33 34.0	-5 16 00	<0.15	...	...	< 2.4
25.....	5 33 34.0	-5 22 00	$\sim$ 0.1	9	$\sim$ 4	< 2.4
26.....	5 33 58.0	-5 22 00	$\sim$ 0.1	9	$\sim$ 4	< 2.4

* Meeks (1971).

contains the 6-cm continuum peak (Mezger and Henderson 1967). The continuum radiation falls off quite rapidly on the scale of Figure 1, and has never been detected below position 12.

A remarkable property of the observed 6-cm absorption is that the expected correlation of line intensity T_L with continuum intensity T_c is entirely absent. Thus, as one proceeds from position 17 off the continuum to the southwest, the line actually increases in intensity, having at position 12 increased in strength $2\frac{1}{2}$ -fold, while T_c has declined from 87° to less than 2° K. This peculiar correlation undoubtedly signifies that it is not the continuum radiation of Ori A which is being absorbed at 6 cm, and that the observed H_2CO lies behind all or most of the H II region. One might be tempted to suppose that the absorbed 6-cm continuum then comes from a second H II layer still more distant than the H_2CO . However, this cannot be the case, for to produce the lines in the lower right-hand corner of Figure 1 this layer would of necessity appear as an arm of Ori A with $T_c > 0.5^{\circ}$ K (and considerably greater than 0.5° K, judging from the unsaturated appearance of the line at position 7); as Table 1 shows, no such arm of the nebula is observed. We are thus led to conclude that it is the microwave background radiation, not H II emission, that is being absorbed at 6 cm, and that we are observing from behind the Orion Nebula the "anomalous" line discovered by Palmer *et al.* (1969) in dark dust clouds.

The continuity in the velocity of the line, and its close agreement with that of the 2-mm H_2CO emission from the infrared nebula, then imply that what is being observed is a more or less continuous sheet of material extending at least from the vicinity of

position 7, where the gas density is presumably rather low, to the very high density ($n_{\text{H}_2} \sim 2 \times 10^5 \text{ cm}^{-3}$) of the infrared nebula. This in turn suggests that the decrease in strength of the anomalous line as one proceeds from position 7 to 17 is *an effect of increasing neutral-particle density*. Of course, other possible explanations for this decrease exist: it might indicate an increase in the fractional ionization (since the effect of electron impact is to heat the 6-cm transition), or it might only indicate a decline in the density of H_2CO ; nevertheless, analysis of the remarkable self-reversed structure of the line at position 17 (Fig. 2) strongly reaffirms the idea that it results from neutral-particle impact.

The first point to note in Figure 2 is that no absorption occurs at 8.5 km s^{-1} , the velocity corresponding to the 2-mm emission from the infrared nebula. This must mean that the anomalous cooling process fails to operate in the infrared nebula, since the amount of H_2CO existing there ($N_{\text{H}_2\text{CO}} \sim 3 \times 10^{14} \text{ cm}^{-2}$, according to Paper II) would be expected to produce an easily detectable $\sim 0.15^\circ \text{ K}$ absorption line if the excitation temperature T_{ex} of the 6-cm levels were only 1.7° K . There are then two possible interpretations of the self-reversed line profile: (i) it represents 6-cm emission from the infrared nebula superposed on a broader anomalous line of about the same intensity, presumably produced by outlying material falling within the $6'$ antenna beam; or (ii) it represents two separate components of anomalous absorption. Interpretation (ii) fails to explain why the reversed core of the profile should match so closely both the velocity and the width of the 2-mm emission, and it requires an improbable, specific breakdown of the cooling process, with T_{ex} equal to exactly 2.7° K , to explain the absence of a line at 8.5 km s^{-1} . Interpretation (i) obviously explains the width and velocity of the core, and

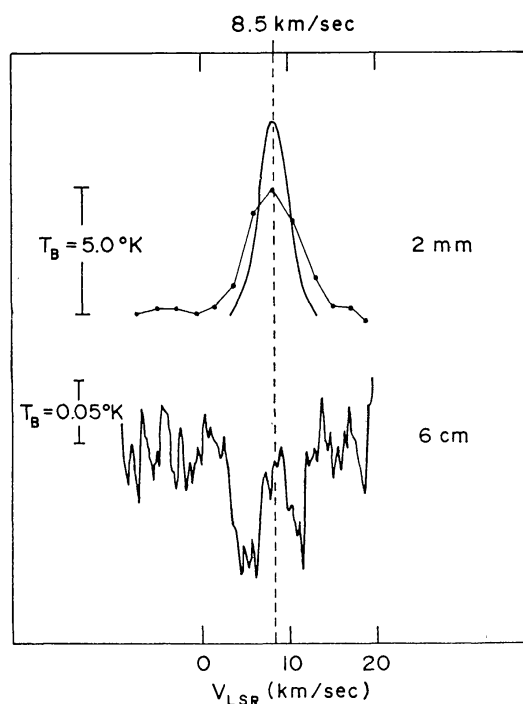


FIG. 2.—Comparison of the 6-cm and the 2-mm line profiles in the direction of the infrared nebula, location 17. The 6-cm profile is an enlargement of that in Fig. 1, and represents a total integration of 420 min. The wide 2-mm profile is the observed 140.8-GHz line from Fig. 1 of Paper II; the narrow one is this profile corrected for the finite spectral resolution of the receiver by assuming that both the true line and the 2-MHz filters in the receiver are Gaussian in shape.

its observed intensity ($\sim 0.12^\circ \text{K}$) is the expected emission if $N_{\text{H}_2\text{CO}} \sim 3 \times 10^{14} \text{ cm}^{-2}$ and $T_{\text{ex}} \gg 2.7^\circ \text{K}$. Interpretation (ii) thus requires a rather improbable set of circumstances whereas interpretation (i) does not, and there can be little doubt that interpretation (i) is the correct one. We thus conclude that the anomalous pumping process is quenched in the infrared nebula, and that 6-cm emission is probably being observed.

Finally, there are several reasons for believing that neutral-particle impact, not electron impact, is responsible for quenching the anomalous cooling process. First, the optical extinction according to Paper II is probably so high that very few ionizing stellar photons penetrate the infrared nebula. Second, the presence of molecules promotes rapid recombination of those electrons which might be produced by X-rays or cosmic rays. Finally, the low observed excitation there of HCN (Snyder and Buhl 1971) and CS (Penzias *et al.* 1971)—molecules whose dipole moments are large—with respect to CO (Wilson, Jefferts, and Penzias 1970)—whose moment is small—indicates that the rate of collisional excitation is not proportional to the rate of radiative decay, as it would be if excitation by electrons were dominant.

In summary, there is now observational evidence that at very high density the pumping process responsible for H_2CO 6-cm anomalous absorption breaks down. This is the expected behavior if the pumping process is radiative, but is contrary to expectation if it is collisional.

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