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DETECTION OF $HC^{17}O^+$ IN SAGITTARIUS B2

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ABSTRACT

Line emission at 87.057 GHz attributed to the $J = 1 \rightarrow 0$ rotational transition of the formyl ion $HC^{17}O^+$ has been detected in Sgr B2 (OH). The $HC^{18}O^+/HC^{17}O^+$ abundance ratio found (3.1 ± 0.6) is lower than the terrestrial $^{18}O/^{17}O$ elemental abundance ratio (5.5) and agrees, within the errors, with the $C^{18}O/C^{17}O$ and $^{18}OH/^{17}OH$ abundance ratios observed in that source.

Subject heading: interstellar: molecules

I. INTRODUCTION

The knowledge of atomic isotope abundances throughout the Galaxy provides important clues to our understanding of the process of nucleosynthesis and galactic evolution. The galactic center region is of particular interest since the processing of gas in stars is thought to have reached an exceptionally high level there.

The oxygen isotopes, ^{16}O, ^{17}O, and ^{18}O, are well suited for this type of study since they are observable in a number of molecular forms. Moreover, ^{16}O, ^{17}O, and ^{18}O have very different nucleosynthetic origins: according to current theories, ^{16}O, the main isotope, is a typical "primary" element formed essentially in the massive stars of the first generation; ^{17}O and ^{18}O, in contrast, are two "secondary" elements released in interstellar space during nova and supernova explosions (Audouze *et al.* 1977). Comparison of the $^{16}O/^{17}O$ and $^{16}O/^{18}O$ abundance ratios in the galactic center region gas with those in the solar system and solar neighborhood helps us to check these theories and tells us about the occurrence of explosive events.

It is unfortunate that the $^{16}O/^{17}O$ and $^{16}O/^{18}O$ ratios (respectively 2750 and 500 in the solar system) are so large that they cannot be measured directly with high accuracy: the opacity in the line of an ^{16}O-bearing molecule is always large when the corresponding line of the ^{17}O species can be detected. In contrast, the $^{18}O/^{17}O$ ratio is only of the order of a few (5.5 in the solar system) and should be measurable with high precision when sensitive enough equipment is used. So far, because of the weakness of the lines, ^{17}O has been observed only in CO and OH. The $C^{18}O/C^{17}O$ abundance ratio has been derived in several giant molecular clouds, on the assumption that it is about equal to the intensity ratio of the $C^{18}O$ to $C^{17}O$ $J = 1–0$ lines (Wannier *et al.* 1976; Penzias 1981). It is found to be approximately the same in the galactic center sources (Sgr B2 and Sgr A) as in the sources of the galactic disk region and 1.5 times smaller than the solar system $^{18}O/^{17}O$ elemental ratio. The ^{17}OH observations toward Sgr B2 and Sgr A seem to support this result (Gardner and Whiteoak 1976; Bujarrabal, Cernicharo, and Guélin 1983).

The finding that the interstellar $^{18}O/^{17}O$ ratio at the same time is constant throughout the Galaxy and differs from the solar system value is surprising in view of the differences in the synthesis of these two elements. The observations have been interpreted to be a result of ^{17}O enrichment in the interstellar medium (Wannier *et al.* 1976). Another proposed interpretation of the observations is that the gas of the presolar nebula has been enriched in the ^{18}O isotope by some local violent event (see, e.g., Penzias 1981). It is clearly desirable to confirm the reported results through observations of another molecule. In this *Letter*, we report the first detection of $HC^{17}O^+$ and estimate the $HC^{18}O^+/HC^{17}O^+$ abundance ratio in the dense core of Sgr B2.

II. $HC^{17}O^+$ 1–0 TRANSITION FREQUENCY

Despite the lack of $HC^{17}O^+$ laboratory study, the center frequency, ν, of the $1 \rightarrow 0$ rotational transition of this species can be fairly accurately calculated, using the data available on other HCO^+ isotopes as well as the vibration-rotation constants computed by Henning, Kraemer, and Dierksen (1977). Following the standard procedure (e.g., Townes and Schawlow 1955), we find

$$B(HC^{17}O^+) = B(HC^{16}O^+)\left|1-\lambda+\lambda\frac{B(HC^{16}O^+)}{B(HC^{18}O^+)}\right|^{-1}$$
$$= 43528.9\ \text{MHz}, \qquad (1)$$

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where B stands for the rotational constants of the HCO^+ isotopes [$B(HC^{16}O^+)$ and $B(HC^{18}O^+)$ are taken from Bogey, Demuynck, and Destombes 1982], and where

$$\lambda = \frac{m(O^{17} - O^{16})}{m(O^{18} - O^{16})} \frac{m(HC^{18}O^+)}{m(HC^{17}O^+)} = 0.5177436 \quad (2)$$

depends only on the masses of the O, C, and H atoms. The distortion constant of $HC^{17}O^+$, to a very good approximation, can be derived from a weighted average of those of $HC^{16}O^+$ and $HC^{18}O^+$ to be $D = 73$ kHz. Then,

$$\nu_0 = 2B - 4D = 87057.5 \text{ MHz}.$$

The uncertainty in ν_0 is quite small. It first comes from the use in equation (1) of effective rotational constants (B_0), whereas this relation strictly applies to the equilibrium constants B_e ($B_0 = B_e - \alpha$, where $\alpha = \frac{1}{2}\Sigma_1^3\alpha_i$ is the rotation-vibration constant). Changing B_e to B_0 in relation (1) supposes that α has the same dependence on mass variation, Δm, as B_e, which is true only to a first approximation. A rough estimate of the error resulting from the B_e to B_0 substitution can be made by assuming that the dependence of α on Δm is the same for HCO^+ and HCN, a molecule isoelectronic with HCO^+ for which accurate measurements exist; we find $\Delta\nu_0 \approx 0.5$ MHz. In comparison, the uncertainties in the B and D values of $HC^{16}O^+$ and $HC^{18}O^+$, resulting from the laboratory measurements, are negligible. We conclude that

$$\nu_0 = 87057.5 \pm 0.5 \text{ MHz}.$$

That the uncertainty in the value of ν_0 is actually much smaller than 0.5 MHz is suggested by parallel calculations carried out on the well-studied molecules, CO, OCS and NNO. Using the laboratory frequencies of the main as well as ^{16}O and ^{18}O isotopes of these species, we obtain values of the $J = 1 \rightarrow 0$ line center frequencies of $C^{17}O$, ^{17}OCS, and $NN^{17}O$ accurate to within few times 10^{-7}.

Owing to the ^{17}O nucleus (spin = 5/2), the $HC^{17}O^+$ $1 \rightarrow 0$ line is split into three hyperfine components, whose relative frequencies depend on the value of the quadrupole coupling constant, *eQq*. This constant is a measure of the strength of the interaction between the ^{17}O nucleus quadrupole moment (Q) and the surrounding charge distribution. Its value can be estimated by scaling up the *eQq* constant of $HC^{14}N$ (whose distribution of charges around the N nucleus should be very similar to that around the ^{17}O nucleus in $HC^{17}O^+$) by the ratio $Q(^{17}O)/Q(^{14}N)$ of the ^{17}O and ^{14}N quadrupole moments (i.e., by a factor -2.6). This yields $eQq = 12$ MHz, a value whose uncertainty could be perhaps as large as 30%. Adopting the ν_0 and *eQq* values so derived leads to the three-line pattern shown in Figure 1*a*.

III. OBSERVATIONS

The observations were carried out at Crawford Hill Laboratory, Holmdel, New Jersey, with the Bell Laboratories (BTL) 7 m telescope during the 1979–1980 and 1981–1982 observing seasons. The antenna resolution, at the frequencies of the $HC^{18}O^+$ and $HC^{17}O^+$ $J = 1$–0 lines (85.2 and 87.1 GHz), was close to 2′. The spectrometer resolution was 1 MHz (3.5 km s^{-1}). A quasi-optical feed system provided rejection of the mixer's image sideband to better than 15 dB. The two spectra of Figure 1 were obtained by switching in position between the source and a reference field and correcting for atmospheric attenuation but not beam efficiency (~ 94% at these frequencies).

Detection of the $HC^{18}O^+$ $J = 0 \rightarrow 1$ line toward Sgr B2 has previously been reported by Guélin and Thaddeus (1979) and by Stark (1981). The spectrum of Figure 1*b* includes the Stark data together with new data also obtained at BTL as part of a survey of the millimeter spectrum of Sgr B2 (Linke, Cummins, and Thaddeus 1983). The $HC^{18}O^+$ line appears simultaneously in emission and in absorption against the continuum source associated with the OH maser. As noted by Guélin and Thaddeus, the narrow ($\Delta V = 13$ km s^{-1}) $HC^{18}O^+$ emission line has a velocity of 54 km s^{-1} similar to that observed for the lines of other rare isotopic species, but lower than the value of 62 km s^{-1} associated with emission from many other molecules in Sgr B2 (see, e.g., Scoville, Salomon, and Penzias 1975). The weak absorption feature, which can be seen between +35 and −45 km s^{-1}, has been shown by Linke, Stark, and Frerking

FIG. 1.—The $J = 1 \rightarrow 0$ transitions of $HC^{17}O^+$ and $HC^{18}O^+$ observed in the direction to Sgr B2 (OH) with a spectral resolution of 1 MHz. (*a*) The $HC^{17}O^+$ transition consists of three hyperfine components whose relative positions and intensities are indicated by the three-line pattern at the bottom of (*a*) (we assume here that $\nu_0 = 87057.5$ MHz, $eQq = 12$ MHz, and $V = 54$ km s^{-1}, see text). The broad line on the right is the $J = 1 \rightarrow 0$ transition of $HN^{13}C$ at 87090.9 MHz; note that the emission of this line, as that of the abundant isotopes $HN^{12}C$ and HCO^+, is strictly limited to velocities lower than 145 km s^{-1} and should not interfere with $HC^{17}O^+$ emission. (*b*) The $HC^{18}O^+$ line appears in emission between 45 and 65 km s^{-1} and in absorption between −45 and +35 km s^{-1}. The line on the left is the $J = 7 \rightarrow 6$ transition of OCS; note that contrary to HCO^+ $J = 1 \rightarrow 0$, the high-J lines of this molecule show no absorption, so that the OCS 7–6 line should not interfere with $HC^{18}O^+$ emission. (*c*) The same spectrum as in (*b*) showing the totality of the 512 MHz instantaneous bandwidth. Molecular line emission in Sgr B2 has been relatively well investigated near 3 mm so that, although the line density is high, the chances of accidental blend with a narrow, unpredicted line are rather low. In the 85.0–85.4 GHz frequency range, only two clear spectral features remain unidentified: the well-known line U85.3 (Thaddeus, Guélin, and Linke 1981), and a weak feature at 85,231 GHz. This latter feature could be a blend of the two strongest $N = 1$–0 hyperfine components of $C^{13}CH$, for which we estimate frequencies of 85,217 and 85,220 (±10 MHz), using the equilibrium structure CI calculations of W. D. Kraemer (1982, private communication).

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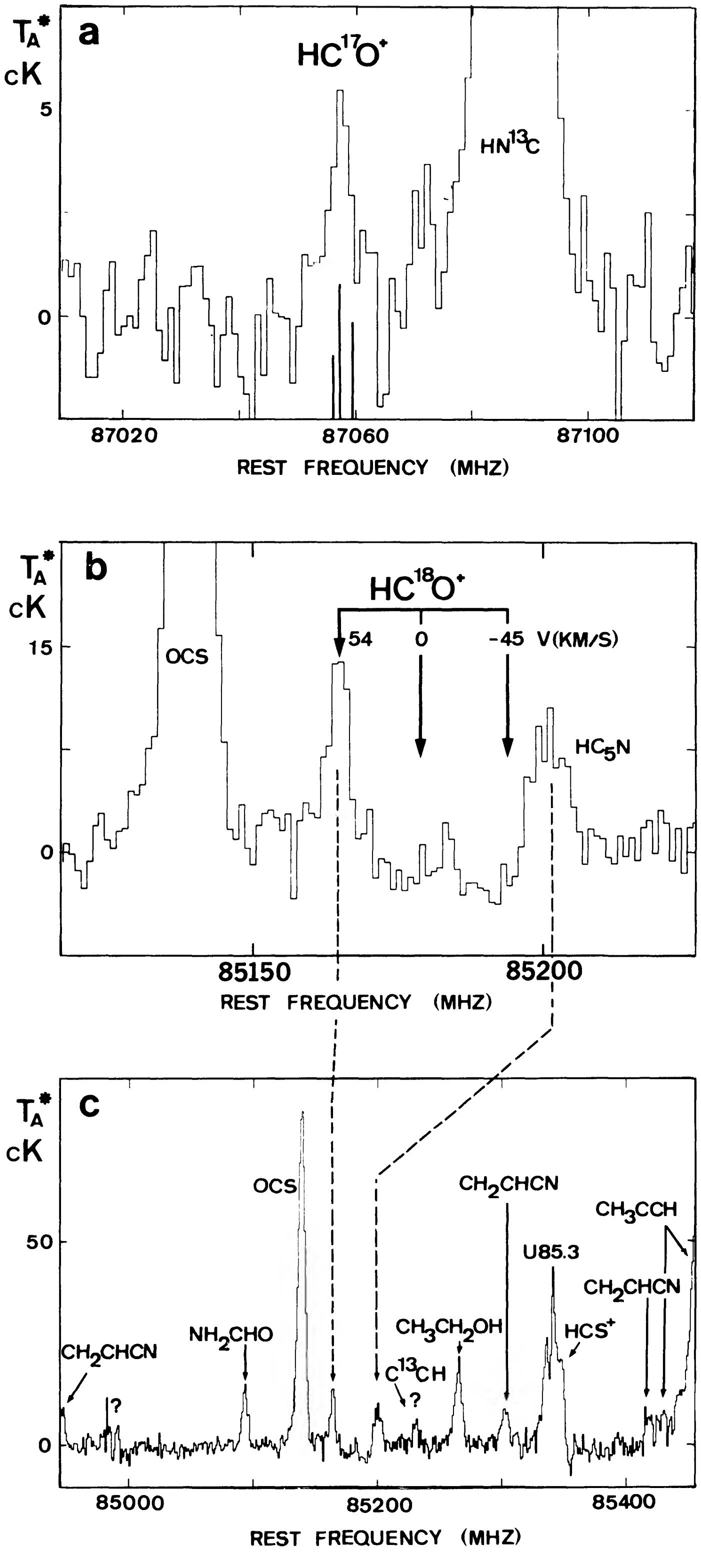

FIG. 1.—See legend on facing page.

(1981) to arise from the gas of the nuclear disk. Absorption features are observed for $H^{13}CO^+$ and HCO^+ down to $V = -125$ km s^{-1}, suggesting that, in Figure 1*b*, $HC^{18}O^+$ absorption is partly blended with the nearby HC_5N line. Between 0 and +30 km s^{-1}, the average absorption depth is −0.02 K, which corresponds to an apparent optical depth $\tau = 0.1$ (vs. 0.3 for $H^{13}CO^+$). The presence of a negative feature adds some uncertainty to the intensity of the emission spike; in Figure 1*b*, the baseline has been defined over a 200 MHz band by discarding the 85.12–85.21 GHz interval (see Fig. 1*c*).

At the frequency predicted for the $J = 1 \rightarrow 0$ transition of $HC^{17}O^+$, a significant feature is present in Figure 1*a*. Since a careful compilation of known or expected interstellar molecules predicts no other line of this strength near ν_0 (or near the frequency corresponding to ν_0 in the image sideband), we identify the new line with $HC^{17}O^+$.

Owing to the closeness of the frequencies of the $HC^{17}O^+$ and $HC^{18}O^+$ lines (which lie less than 2 GHz apart) and to the reliable line calibration procedure in use on the Holmdel telescope, the temperature scales of the $HC^{18}O^+$ and $HC^{17}O^+$ spectra are directly comparable with relative calibration errors expected to be no greater than 5%. The antenna temperature ratio should, therefore, be equal within the noise to the line intensity ratio. This latter ratio, averaging the three central channels of each line, is found to equal 3.1 ± 0.4 where the error reflects statistical uncertainty. This intensity ratio accurately reflects the $HC^{18}O^+/HC^{17}O^+$ column density ratio in Sgr B2 only if: (1) $HC^{18}O^+$ emission in the 54 km s^{-1} Sgr B2 cloud is optically thin; (2) the disk foreground absorption is negligible at this velocity—or at least affects similarly the $HC^{17}O^+$ and $HC^{18}O^+$ lines; (3) the intensity of the $HC^{17}O^+$ line is not decreased by hyperfine splitting; and (4) there is no isotope fractionation. The first two conditions are likely to be fulfilled, or at least are unlikely to lead to a large (> 20%) error: the $HC^{13}O^+/HC^{18}O^+$ brightness ratio at 50–54 km s^{-1} (3–4) approaches two-thirds of the $(^{13}C : {}^{12}C)/(^{18}O : {}^{16}O)$ double isotopic ratio in Sgr B2 (6 from the H_2CO observations of Henkel, Wilson, and Downes 1979); yet, this ratio should be much more sensitive to the effects of line opacity than the $HC^{18}O^+/HC^{17}O^+$ ratio, since the optical depth is a factor of 6 larger for $HC^{13}O^+$ than for $HC^{18}O^+$. Hyperfine splitting, in principle, can reduce the peak intensity of the $HC^{17}O^+$ line by as much as 50% (see Fig. 1); in the case of Sgr B2, however, the line width (4.5 MHz according to the $HC^{18}O^+$ spectrum) is too broad to allow the resolution of the two strongest hyperfine components. For $eQq = 12$ MHz, the value estimated above, the line peak intensity is still 80% of the unsplit value and the 3 MHz averaged intensity is even closer; an important effect (e.g., intensity reduced to 70% of its unsplit value) arises only for improbably large values of eQq (> 20 MHz). In fact, there is no evidence, according to Figure 1*a*, that the $HC^{17}O^+$ line is any broader than the $HC^{18}O^+$ line, which suggests that eQq actually is smaller than 12 MHz. Combining the uncertainty in the $R = H^{18}CO^+/HC^{17}O^+$ abundance ratio due to the receiver noise with the errors introduced by hyperfine splitting and possible $HC^{18}O^+$ line opacity (two errors of opposite sign which in fact should partly balance each other), we derive

$$R = HC^{18}O^+/HC^{17}O^+ = 3.1 \pm 0.6.$$

Note that the use of the line-integrated intensity ratio instead of the 3 MHz smoothed peak intensity ratio would not have improved the accuracy of R since the total widths of the lines and the $HC^{18}O^+$ baseline are not well defined.

In addition to observing Sgr B2 emission, we have searched for $HC^{17}O^+$ in Orion A and NGC 2264. The limits derived in these sources, where the $HC^{18}O^+$ line is very weak, are, however, too high to be meaningful (they yield: $R > 2$).

Two reasons make it unlikely that the observed $^{18}O/^{17}O$ ratio in Sgr B2 is altered by chemical fractionation. First, there seems to be no known isotope exchange reaction capable of efficiently enhancing ^{17}O or ^{18}O in CO in the cold dense clouds (see, e.g., Guélin, Langer, and Wilson 1982). Second, even if such a reaction were to exist, it should affect the HCO^+, CO, and OH data unequally: isotope exchange reactions are sensitive to temperature, and the lines of these three molecules are known to arise from regions with very different physical conditions (in fact, as already noted, the center velocity of the $HC^{17}O^+$ and $HC^{18}O^+$ lines differ from those of the CO and OH lines). Finally, mass fractionation mechanisms, as well as selective CO photodissociation (Bally and Langer 1982), might increase the $^{18}O/^{17}O$ ratio but could not be responsible for an artificially depressed value.

Within the errors, the $HC^{18}O^+/HC^{17}O^+$ abundance ratio in Sgr B2 (3.1 ± 0.6) is thus found to equal the $C^{18}O/C^{17}O$ ratios of 3.2 ± 0.2 and 3.6 ± 0.1 reported by Wannier *et al.* (1976) and Penzias (1981) and the $^{18}OH/^{17}OH$ ratio (3.5 ± 0.5, Bujarrabal, Cernicharo, and Guélin 1983). It is a factor of ~ 1.8 smaller than the solar system $^{18}O/^{17}O$ elemental abundance ratio (5.5).

IV. DISCUSSION

It is customary to refer to the solar system isotopic abundance values as representative of those in the interstellar gas some 5 billion years ago. In that case, the factor of ~ 1.5 difference between the solar and the interstellar $^{18}O/^{17}O$ ratios reflects an abundance change since that epoch, due to stellar processing of the gas. Then, one would expect some measurable change between the highly processed gas of the galactic center region and the gas of the remote parts of the galactic disk, a change which is not supported by the data (Penzias 1981).

This difficulty could be lessened if efficient mixing of the interstellar gas on the scale of the entire galaxy were to take place in a time of a billion years. Alternatively, as suggested by Penzias (1981), it could mean that the presolar nebula (whose mass was very small compared with the mass of the molecular clouds) was enriched in ^{18}O. Such enrichment would be the result of a nearby supernova explosion. In fact, the small anomalies in oxygen isotope abundances, observed in some meteorites, have been interpreted as evidence of such an explosion (see Clayton 1977).

Unfortunately, there are formidable theoretical difficulties associated with each of these proposals. Clearly more theoretical as well as observational work is required before this challenging question can be settled.

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