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A SEARCH FOR INTERSTELLAR OXIRANECARBONITRILE (C_3H_3NO)

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Abstract. We report a search in cold, quiescent and in 'hot core' type interstellar molecular clouds for the small cyclic molecule oxiranecarbonitrile (C_3H_3NO), which has been suggested as a precursor of important prebiotic molecules. We have determined upper limits to the column density and fractional abundance for the observed sources and find that, typically, the fractional abundance by number relative to molecular hydrogen of C_3H_3NO is less than a few times 10^{-10}. This limit is one to two orders of magnitude less than the measured abundance of such similarly complex species as CH_3CH_2CN and $HCOOCH_3$ in well-studied hot cores. A number of astrochemical discoveries were made, including the first detection of the species CH_3CH_2CN in the massive star-forming clouds G34.3+0.2 and W51M and the first astronomical detections of some eight rotational transitions of CH_3CH_2CN, CH_3CCH, and $HCOOCH_3$. In addition, we found 8 emission lines in the 89 GHz region and 18 in the 102 GHz region which we were unable to assign.

Introduction

The vast majority of the more than one hundred molecular species indentified in interstellar clouds are organic in their nature (Irvine, 1995). This gives testament to the complex chemistry taking place in these regions. The identification and abundance determinations for new molecules provide important constraints to the various models which have been introduced to study the chemical evolution in these clouds (cf. Millar *et al.*, 1991; Herbst and Leung, 1989; Herbst, 1995). Moreover, molecular clouds are the birthplaces of stars and planetary systems. Therefore, information about the chemical processes in these clouds is of fundamental importance in the study of the origin and evolution of our solar system, and, conceivably, of life on Earth.

An active area of current research in this endeavor is the study of whether prebiotic molecules were synthesized *in situ* in the Earth's environment or whether some may have been introduced from outside. Chemical models of the early atmosphere of the Earth have long suggested an oxidation-reduction state dominated by carbon dioxide (e.g., Goldschmidt, 1945), rather than the strongly reducing atmosphere which greatly facilitates prebiotic synthesis of organic molecules in the Earth's atmosphere (e.g., Miller and Urey, 1959; Ponnamperuma, 1983). Because of the

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difficulty in achieving effective synthesis in a redox-neutral atmosphere, attention has been increasingly drawn to an extraterrestrial origin of source molecules for complex organic compounds (e.g., Kasting, 1993; Chyba and Sagan, 1992). Cronin and Chang (1993) discuss the evidence for survival of interstellar molecules in carbonaceous chondrites and cometary nuclei, including certain prebiotic molecules (cf. Thomas, 1992).

In the course of an extensive study towards a prebiotic rationalization of the nucleic acid structure, A. Eschenmoser and collaborators have demonstrated that glycolaldehyde phosphate is an effective precursor for the synthesis of sugar phosphates (e.g., Eschenmoser and Loewenthal, 1992). Significantly, the main product of its reaction with half an equivalent of formaldehyde in alkaline, aqueous solution is racemic ribose 2,4-diphosphate, the backbone component of p-RNA. It was also shown that glycolaldehyde phosphate can be synthesized in high yield from oxiranecarbonitrile and inorganic phosphate in aqueous solution (Pitsch *et al.*, 1994).

Oxiranecarbonitrile is a cyclic molecule consisting of a C-O-C ring, with a CN group attached to one of the carbons, and is otherwise completely saturated. Although not many relevant reactions have been studied in the laboratory, Pitsch *et al.* (1994) suggest that two possible photochemically activated pathways to the formation of oxiranecarbonitrile might be carbon monoxide (CO) plus methyl cyanide (CH_3CN) or formaldehyde (H_2CO) plus the cyanomethyl radical (CH_2CN), all four of which are known interstellar molecules. In terms of current models of ion-molecule interstellar chemistry, an alternative route might involve protonated ethyl cyanide ($CH_3CH_2CNH^+$) reacting with atomic oxygen, followed by dissociative electron recombination (E. Herbst, private communication). The likelihood for ion-molecule reactions, rather than photochemical processes, was pointed out by Arrhenius *et al.* (1995), with the suggestion that interstellar cloud conditions, with respect to the possible formation of oxiranecarbonitrile, could approach those in the auroral zone of the Archean ionosphere in the polar dark season.

The detection of oxiranecarbonitrile would, therefore, be an important and exciting contribution to both the study of prebiotic synthesis and to interstellar chemistry. In the latter context, it would increase the number of identified interstellar cyclic molecules, chemical structures which may have been important as activated species in prebiotic geochemistry, from the current three (C_3H_2, SiC_2, and c-C_3H; several broad interstellar infrared features may arise from polycyclic aromatic species, but detailed assignments have not yet been possible).

Oxiranecarbonitrile

C_3H_3NO is a prolate asymmetric rotor with components of the electric dipole moment along all three principal axes. The μ_a component is twice as large as

Table I
Oxiranecarbonitrile transitions observed

Transition	Frequency (MHz)	Telescope	η_b	HPBW (arcsec)
$5_{0,5}$–$4_{0,4}$	34437.432	NEROC	0.45	60
$6_{0,6}$–$5_{0,5}$	41311.141	NEROC	0.42	50
		NRO	0.66	40
$7_{0,7}$–$6_{0,6}$	48177.406	NEROC	0.38	42
$13_{0,13}$–$12_{0,12}$	89162.683	NRO	0.39	19
$15_{0,15}$–$14_{0,14}$	102729.760	NRO	0.38	16

Notes: η_b is the telescope main beam efficiency; HPBW is the half-power beam width at the observing frequency.

the others, with a value of 2.98 D. The rotational spectrum of C_3H_3NO has been investigated recently in the laboratory by two of us (Müller and Bauder, 1995).

The 5_{05}–4_{04}, 6_{06}–5_{05}, and 7_{07}–6_{06} rotational transitions are ≈5 K, 7 K, and 9 K above the ground state with frequencies between 34 and 48 GHz, where sensitive radio receivers are available. Quiescent dark clouds, where the kinetic temperatures are on the order of 10 K, exhibit a rich chemistry which has been reasonably well matched by gas phase ion-molecule chemical models (e.g., Irvine, 1992; Herbst, 1995). A number of nitriles, such as the cyanopolyynes, have been detected in dark clouds. Although most of these species are quite unsaturated, we felt that searches for C_3H_3NO in such regions were important.

With the exception of the CN triple bond, oxiranecarbonitrile is completely saturated. Hence, we also searched at higher frequencies in 'hot-core' type sources where related molecules, such as ethyl cyanide (CH_3CH_2CN), are abundant (Charnley *et al.*, 1992; Caselli *et al.*, 1993). The higher kinetic temperatures in these sources (≈50–100 K) allow additional reaction pathways, and, perhaps, release of molecules from grain surfaces, providing the potential for a more complex chemistry.

Observations

The observations were made in October 1994 and May 1995 with the NEROC Haystack 37-meter telescope in Massachusetts, USA, and in February 1995 with the Nobeyama Radio Observatory (NRO) 45-meter telescope in Japan. The observed frequencies and telescope parameters are summarized in Table I. Our list of sources is included as Table II.

We used the NEROC 7 mm cooled maser preamplifier receiver, which gave average system temperatures of 370 K, to observe the 34 and 48 GHz regions. The autocorrelation spectrometer used a 17.8 MHz bandwidth, which produced 8.7 kHz resolution. We observed the 41 GHz transition with the NEROC 7 mm

Table II
Interstellar cloud list

Source	RA (1950)	DEC (1950)	VLSR (km s^{-1})
Dark cloud sources			
TMC1(NH_3)	$04^h38^m16.6^s$	+25°42′45.0″	+ 5.9
TMC1(CP)	$04^h38^m38.6^s$	+25°35′45.0″	+ 5.9
L134N	$15^h51^m34.0^s$	−02°40′31.0″	+ 2.5
B335	$19^h34^m35.0^s$	+07°27′30.0″	+ 8.4
Hot core sources			
Orion-KL	$05^h32^m46.9^s$	−05°24′23.6″	+ 9.0
SgrB2(N)	$17^h44^m10.6^s$	−28°21′05.0″	+60.0
G34.3+0.2	$18^h50^m46.2^s$	+01°11′13.0″	+60.0
W51M	$19^h21^m26.3^s$	+14°24′36.0″	+53.0
NGC7538	$23^h11^m36.6^s$	+61°11′47.0″	−60.0
Circumstellar envelope			
IRC+10216	$09^h45^m15.0^s$	+13°30′45.0″	+26.3

Notes: coordinates given as right ascension (RA) and declination (DEC); VLSR is the cloud velocity with respect to the local standard of rest.

HEMT amplifier receiver. This dual-channel system allowed us to observe two polarizations simultaneously, which we later added together to improve the signal-to-noise ratio. System temperatures with the HEMT receiver were consistently near 175 K. All of these observations were carried out in frequency-switching mode, so that the source region was always in the telescope beam. The frequency switching interval was ± 4.4 MHz (one-quarter the bandwidth), chosen to suppress any baseline irregularities. The telescope pointing was checked every 2 hours by continuum observations of planets.

At Nobeyama, we used SIS mixer receivers in the 41, 89, and 102 GHz regions with average system temperatures of 200 K, 350 K, and 400 K, respectively. Two sets of acousto-optical spectrometer (AOS) systems are available at Nobeyama: wide-band (AOS-wide) and high-resolution (AOS-high). Each of the former has a 250 MHz bandwidth and 250 kHz resolution, while each of the AOS-highs has a bandwidth of 40 MHz and 37 kHz resolution. For the 89 and 102 GHz observations we used the AOS-wide set-up and were able to observe both frequency regions simultaneously, obtaining spectra over a range of 750 MHz centered about 89 GHz and 102 GHz. Although we concentrated on hot cores at Nobeyama, we did observe the dark cloud TMC-1 in the 41 GHz range. For this source, with its anticipated narrow lines, we switched to AOS-high. For all of these observations, the spectra were taken in position-switching mode. The telescope pointing was checked every 2 hours by observing interstellar SiO masers near the sources.

As is usual in radio astronomy, the line intensities are measured in terms of T_a^*, the antenna temperature corrected for atmospheric attenuation and telescope losses in the forward hemisphere (cf. Kutner and Ulich, 1981). We relate this quantity to the radiation temperature, T_R (which may in turn be related to the number of molecules in the line of sight; equation (1) below) by assuming that $T_R \approx \frac{T_a^*}{\eta_B}$, where η_B is the main-beam efficiency of the telescope as determined by observations of planets whose brightness temperatures are known (Table I). In the Raleigh-Jeans limit ($\frac{h\nu}{kT} << 1$, where ν is the frequency), T_R is related to the specific intensity of line emission, I_ν (erg s^{-1} cm^{-2} Hz^{-1} Sr^{-1}), by $I_\nu = \frac{2kT_R}{\lambda^2}$.

Results

No emission from oxiranecarbonitrile was definitely detected. To calculate upper limits on its abundance, we proceed as follows. The integral over the radiation temperature may be related to the number of molecules of interest per cm^2 along the line of sight, called the column density. Column densities, N_u (cm^{-2}), for the number of molecules in the upper energy level of a transition were calculated using the standard equation (cf. Irvine *et al.*, 1987), which assumes optically thin emission, plus a term to correct for the emission due to the background continuum radiation:

$$N_u = 10^5 \left(\frac{8\pi k\nu^2}{hc^3 A_u}\right) \left[1 - \frac{\exp(h\nu/kT_{\rm exp}) - 1}{\exp(h\nu/kT_{\rm BG}) - 1}\right]^{-1} \int T_R dv, \qquad (1)$$

where $\int T_R dv$ (K km s^{-1}) is the total integrated line intensity, ν (Hz) is the transition frequency, A_u (s^{-1}) is the Einstein spontaneous emission coefficient for the transition, $T_{\rm BG}$ is the microwave background radiation temperature ($T_{\rm BG}$ = 2.7 K), and k, h, and c are Boltzmann's constant, Planck's constant, and the speed of light, respectively. $T_{\rm ex}$, the excitation temperature, is defined through the relative populations of the upper ($n_{\rm u}$) and lower ($n_{\rm l}$) energy levels of the transition by

$$\frac{n_{\rm u}}{n_{\rm l}} = \frac{g_{\rm u}}{g_{\rm l}} \exp\left(\frac{-h\nu}{kT_{\rm ex}}\right), \qquad (2)$$

where g_i is the degeneracy of the ith level ($g_i = 2J_i + 1$, for J_i equal to the total angular momentum quantum number specifying the energy level).

The total molecular column density, N, is related to the upper level column density by

$$N = \frac{N_{\rm u} Q(T_{\rm ex})}{g_{\rm u}} \exp\left(\frac{E_{\rm u}}{kT_{\rm ex}}\right), \qquad (3)$$

where E_u is the energy of the upper level above the ground state and $Q(T_{ex})$ is the partition function at T_{ex},

$$Q(T_{ex}) = \sum g_i \exp\left(\frac{-E_i}{kT_{ex}}\right) \tag{4}$$

(e.g., Townes and Schawlow, 1975). Of course, this relation assumes that the energy levels are populated according to a Boltzmann distribution and that a single excitation temperature T_{ex} can describe that distribution. However, without more specific information on the excitation conditions of the molecule, we must make this assumption. The partition function was determined by direct summation over the energy levels, including centrifugal distortion, as a function of excitation temperature. The summation was stopped at a given J level, when the next higher J contributed less than 10^{-6} to the total partition function.

For the dark cloud sources, we calculated upper limits to the column densities by assuming a linewidth $\Delta v = 0.5$ km s^{-1}, consistent with the values for emission from other high dipole-moment, optically thin molecular lines (e.g., C_3HD, Madden, 1990; $H_2{}^{13}CO$, Minh *et al.*, 1995). For the hot cores, we took the following values (Δv[km s^{-1}]; T_{ex}[K]; reference) from the literature, emphasizing, where possible, molecules with complexity similar to C_3H_3NO, such as CH_3CH_2CN: Orion-KL (10; 115; Johansson *et al.*, 1984); SgrB2(N) (15; 100; Sutton *et al.*, 1991); G34.3 + 0.2 (8; 100; Macdonald *et al.*, 1995); W51M (10; 100; Andersson, 1985); and NGC 7538 (5; 50; Andersson, 1985). These linewidths are consistent with those measured here (Table V). The upper limit to the integral in equation (1) was calculated as $3\sigma\Delta v/\sqrt{m}$, where σ is the rms per channel in the T_R spectrum, Δv is the linewidth just described above, and m is the number of channels included in Δv. The upper limit to the column density scales as the 1.5 power of the assumed T_{ex} for the hot core sources due to the ${T_{ex}}^{3/2}$ dependence of $Q(T_{ex})$ (Townes and Schawlow, 1975). The limit is less sensitive to the assumed value of T_{ex} for the dark clouds since the term T_{BG} in equation (1) tends to cancel the effect of Q, given that T_{ex} and T_{BG} are comparable.

To convert column densities to fractional abundances by number with respect to molecular hydrogen, we define $f(C_3H_3NO) \approx \frac{N(C_3H_3NO)}{N(H_2)}$. Although these abundances strictly refer to averages along the entire line of sight, almost all the relevant molecules will be in the targeted sources. The molecular hydrogen column densities used in the above expression were obtained from the literature, noting that the telescope beam size Θ_B for our hot core observations is $\approx 18''$ and for our dark cloud observations is $\approx 40''$ and that estimates of $N(H_2)$ should be for similar-sized angular regions. For the Orion hot core, we interpolate a value of 3×10^{23} cm^{-2} (Blake *et al.*, 1986, $\Theta_B \approx 30''$; Masson *et al.*, 1985, source size $\approx 10''$). A value of 3×10^{24} cm^{-2} is found for SgrB2(N) from Lis and Goldsmith (1991; $\Theta_B \approx 45''$) and Martin-Pintado *et al.* (1990; source size $\approx 5''$). For a beam similar to ours ($\approx 14''$), Millar *et al.* (1995) estimate $N(H_2) \approx 5 \times 10^{23}$ cm^{-2} for G34.3 + 0.15. We adopt the estimate of Millar *et al.* (1988) of $N(H_2) \approx 2 \times 10^{23}$ cm^{-2} for W51M, although

Table III

Upper limits for C_3H_3NO in dark clouds

Source/ transition	T_a^* (mK)	N_u (C_3H_3NO) (cm^{-2})	f(C_3H_3NO)
TMC1-NH$_3$			
$5_{0,5}$–$4_{0,4}$	$\leq$90	$\leq$1.33(11)	
$6_{0,6}$–$5_{0,5}$	48	5.56(10)	
$6_{0,6}$–$5_{0,5}$[a]	42	3.89(10)	$\leq$1.6(−10)
$7_{0,7}$–$6_{0,6}$	138	1.35(11)	
TMC1-CP			
$5_{0,5}$–$4_{0,4}$	123	1.82(11)	5.7(−10)
L134N			
$5_{0,5}$–$4_{0,4}$	102	1.51(11)	
$6_{0,6}$–$5_{0,5}$	54	6.26(10)	3.3(−10)
$7_{0,7}$–$6_{0,6}$	231	2.26(11)	
B335			
$5_{0,5}$–$4_{0,4}$	114	1.69(11)	
$6_{0,6}$–$5_{0,5}$	63	7.30(10)	5.1(−10)
$7_{0,7}$–$6_{0,6}$	261	2.56(11)	

Notes: all values in this table are 3σ uncertainty upper limits. T_a^* is antenna temperature, N_u is column density in the upper energy level of the transition, and f is fractional abundance by number relative to molecular hydrogen. Column density assumed for H_2 discussed in text. We denote the value $A \times 10^B$ as A(B). The most stringent value for the fractional abundance for each source is listed.

[a] This datum is taken at NRO.

it nominally refers to a source size ($\approx$10″) somewhat smaller than our beam. For the last hot core, NGC7538, we take $N(H_2) \approx 8 \times 10^{23}$ cm^{-2} from unpublished NRO data by O. Kameya (private communication). For the dark clouds, we adopt the values of Butner *et al.* (1995) for L134N and B335 (8×10^{21} and 6×10^{21} cm^{-2}, respectively) and take the standard value of 10^{22} cm^{-2} for both TMC-1 positions (Irvine *et al.*, 1987), noting that $C^{18}O$ emission is rather uniform across this source (Friberg and Hjalmarson, 1990).

Upper limits to the column density and fractional abundance relative to molecular hydrogen are summarized in Table III (dark clouds) and Table IV (hot cores). Comparing to abundances of detected species, we find, for example, that C_3H_3NO is at least a factor of 20 less abundant than cyclic C_3H_2 at the observed dark cloud positions (Ohishi *et al.*, 1992; Madden, 1990; Swade, 1987), and is at least an order of magnitude less abundant than CH_2C_2H in TMC-1. As can be seen from Tables III and IV, we typically obtained fractional abundance upper limits that were somewhat more sensitive for the hot core sources. These upper limits for C_3H_3NO are

Table IV

Upper limits for C_3H_3NO in hot core sources

Source	Transition	T_a^* (mK))	$N_u(C_3H_3NO)$ (cm^{-2})	$f(C_3H_3NO)$
Orion-KL	$13_{0,13}-12_{0,12}$	≤ 66	$\leq 1.55(11)$	
	$15_{0,15}-14_{0,14}$	54	1.05(11)	$\leq 2.2(-10)$
SgrB2(N)	$13_{0,13}-12_{0,12}$	48	1.39(11)	
	$15_{0,15}-14_{0,14}$	72	1.70(11)	2.6(−11)
G34.3+0.2	$13_{0,13}-12_{0,12}$	87	1.86(11)	
	$15_{0,15}-14_{0,14}$	57	9.67(10)	1.1(−10)
W51M	$13_{0,13}-12_{0,12}$	39	9.17(10)	
	$15_{0,15}-14_{0,14}$	63	1.22(11)	2.6(−10)
NGC7538	$13_{0,13}-12_{0,12}$	33	5.67(10)	
	$15_{0,15}-14_{0,14}$	48	6.78(10)	1.9(−11)

Notes: all values in this table are 3σ uncertainty upper limits. Same notation as in Table III. The most stringent value for the fracgtional abundance determined from these two transitions is listed for each source.

about two orders of magnitude smaller than the observed fractional abundance for similarly complex molecules, such as CH_3CH_2CN and $HCOOCH_3$, in Orion-KL and SgrB2 (cf. Blake *et al.*, 1987; Turner, 1991).

For the circumstellar envelope IRC+10216, we report an upper limit to the column density for both the $13_{0,13}$ and $15_{0,15}$ levels of about $N_u \approx 2 \times 10^{11}$. Since we found no information about the excitation conditions for molecules similar to C_3H_3NO in this source, we did not calculate the total column density. In fact, the concept of an abundance for a molecule along a particular line of sight does not apply here, due to the spherical distribution of gas and strong radial variations in physical and chemical conditions in this circumstellar envelope.

As a byproduct of the search at NRO, we observed 750 MHz around the C_3H_3NO frequencies of interest and detected molecular transitions from several other species. In particular, we report what is to our knowledge the first detection of the molecule CH_3CH_2CN in the massive star-forming regions (hot cores) G34.3+0.2 and W51M. In addition, we report the first astronomical detections of certain transitions attributable to CH_3CH_2CN, CH_3CCH, and $HCOOCH_3$ and a tentative first astronomical detection of the ^{18}OCS isotopomer. The observed spectral features are listed in Table V and are arranged by source. Twenty-seven distinct features at least 5σ in strength were unassigned, and they are denoted as U (unidentified) in Table V. Five of these U-line transitions were detected in more than one source (e.g., the U-line near 102.555 GHz was detected in Orion-KL, G34.3+0.2, and W51). We also determined that several of our spectral lines result from image sideband leakage, and they are denoted as I in Table V. Image frequencies were calculated as f(image)=175520[MHz]-f(signal) for lines in the 89 GHz region and f(image)=208260[MHz]-f(signal) for the 102 GHz region. We note that

Table V

Detected emission lines

Source Frequency (MHz)	Molecule	Transition	T_a^* (K)	Δv (km s^{-1})
TMC1-NH$_3$				
41376.270	U[a]		0.094	1.29
102546.102	CH_3CCH	6(1)–5(1)	0.183	0.91
102548.117	CH_3CCH	6(0)–5(0)	0.199	0.83
Orion KL				
88862.789	$HCOOCH_3$	unassigned[c]	0.272	2.68
88879.805	I[SO_2	8(3,5)–9(2,8)]	0.220	11.42
88896.188	CH_3CH_2CN[a]	19(1,18)–19(0,19)	0.076	6.77
88903.547	I[CH_3OH	7(2)–6(3) A^-]	0.269	3.69
88940.500	CH_3OH	15(3)–14(4)A^-	2.187	4.11
88998.828	$HCOOCH_3$	unassigned[c]	0.273	2.00
89010.773	CH_3CH_2CN[a]	25(2,23)–25(1,24)	0.107	6.78
89140.820	CH_3OH	45(–11)–44(–12) E ?	0.279	1.91
89188.570	HCO^+	1–0	13.241	4.39
89272.422	I[SiO	ν=1,J=2–1]	2.151	4.48
89278.094	I[SiO	ν=1,J=2–1]	1.542	5.82
89298.727	CH_3CH_2CN	10(2,9)–9(2,8)	1.079	9.69
89317.031	$HCOOCH_3$	8(1,8)–7(1,7) A+E[b]	1.480	3.06
89325.078	$^{13}CH_3CN$[a]	5(2)–4(2)	0.168	5.14
89331.719	$^{13}CH_3CN$	5(1)–4(1)/5(0)–4(0)[b]	0.290	9.90
89341.523	U[a]		0.160	14.85
89369.828	U[a]		0.185	11.38
89425.953	I[SO	2(2)–1(1)]	0.362	24.29
89506.195	CH_3OH	8(–4)–9(–3) E	3.008	3.70
102473.164	U[a]		0.084	4.32
102489.867	$HCOOCH_3$	unassigned[c]	0.244	4.17
102503.633	$HCOOCH_3$	unassigned[c]	0.407	2.54
102517.281	CH_3CCH[a]	6(4)–5(4)	0.077	4.66
102530.625	CH_3CCH	6(3)–5(3)	0.294	4.72
102534.398	$^{13}CH_3OH$	unassigned[c]	0.257	3.43
102540.312	CH_3CCH	6(2)–5(2)	0.300	3.67
102548.242	CH_3CCH	6(1)–5(1)/6(0)–5(0)[b]	0.722	4.46
102555.164	U[a]		0.292	4.37
102562.844	U[a]		0.199	3.77
102658.523	CH_3OH	11(–2)–11(1) E	1.616	3.56
102683.648	^{18}OCS[a]	9–8 ?	0.155	5.77
102690.969	SO_2	33(8,26)–34(7,27)	0.140	6.29
102704.742	U[a]		0.075	2.00
102734.695	$HCOOCH_3$	16(5,11)–16(4,12) E	0.317	1.77

Table V
(*Continued.*)

Source Frequency (MHz)	Molecule	Transition	T_a^* (K)	Δv (km s^{-1})
102737.352	$HCOOCH_3$	16(5,11)–16(4,12) A	0.296	2.30
102897.531	$HCOOCH_3$[a]	6(2,5)–5(1,4) E	0.180	2.02
102902.219	U[a]		0.036	4.50
102909.812	$HCOOCH_3$[a]	6(2,5)–5(1,4) A	0.187	1.65
102912.852	U[a]		0.082	3.61
102958.211	CH_3OH	unassigned	1.107	3.62
103012.961	$HCOOCH_3$	unassigned[c]	0.092	4.07
103022.977	U[a]		0.100	3.98
IRC + 10216				
88916.227	C_5H	$^2\Pi_{3/2}$ J=37/2–35/2 e+f[b]	0.067	–
89045.812	C_3N	N=9–8, J=19/2–17/2	0.833	28.88
89064.625	C_3N	N=9–8, J=17/2–15/2	0.869	28.88
89087.953	HCN	1–0 l=0 F=2–1 ν_2=2	0.278	19.25
89103.664	^{29}SIS	5–4	0.175	28.88
SgrB2				
88891.258	U[a]		0.179	15.09
88904.836	I [CH_3OH	7(2)–6(3) A^-]	0.092	16.68
88938.742	CH_3OH	15(3)–14(4) A^-	0.618	17.56
89008.242	CH_3CH_2CN[a]	25(2,23)–25(1,24)	0.204	17.11
89045.500	C_3N	N=9–8, J=19/2–17/2	0.035	–
89064.297	C_3N	N=9–8, J=17/2–15/2	0.133	15.04
89085.906	HCN	1–0 l=0 F=1–1 ν_2=2	0.267	19.23
89139.148	$HCOOCH_3$	unassigned[b]	0.313	17.17
89151.016	CH_3OH	unassigned[c]	0.133	18.28
89179.281	HCO^+	1–0	–	–
89263.773	U[a]		0.217	18.75
89296.266	CH_3CH_2CN	10(2.9)–9(2,8)	0.865	17.28
89315.086	$HCOOCH_3$	8(1,8)–7(1,7) A+E[b]	0.777	15.37
89328.227	$^{13}CH_3CN$	5(1)–4(1)/5(0)–4(0)[b]	0.732	22.08
89339.305	U[a]		0.503	22.18
89367.516	U[a]		0.315	13.64
89414.195	$HCOOCH_3$	11(1,10)–11(1,11) E	0.230	19.27
89504.641	CH_3OH	8(–4)–9(–3) E	0.665	17.85
102488.102	$HCOOCH_3$	unassigned[c]	0.159	16.45
102501.742	$HCOOCH_3$	unassigned[c]	0.080	13.11
102529.164	CH_3CCH	6(3)–5(3)	0.396	16.13
102544.102	CH_3CCH	6(1)–5(1)/6(0)–5(0)[b]	0.867	20.05
102559.961	U[a]		0.180	11.98
102656.508	CH_3OH	11(–2)–11(1) E	0.444	16.74

Table V

(*Continued.*)

Source Frequency (MHz)	Molecule	Transition	T_a^* (K)	Δv (km s^{-1})
102815.234	U[a]		0.128	15.51
102907.266	$HCOOCH_3$[a]	6(2,5)–5(1,4) A	0.133	15.09
102926.008	U[a]		0.0065	16.66
102956.289	CH_3OH	unassigned	0.308	17.77
103020.930	U[a]		0.107	19.84
G34.3+0.2				
88866.500	$H^{15}NC$	1–0	0.097	5.12
88940.266	CH_3OH	15(3)–14(4) A^-	0.181	7.65
89189.602	HCO^+	1–0	5.240	5.10
89298.453	CH_3CH_2CN	10(2,9)–9(2,8)	0.097	4.90
89316.758	$HCOOCH_3$	8(1,8)–7(1,7) A+E[b]	0.109	5.20
89505.789	CH_3OH	8(–4)–9(–3) E	0.249	7.22
102490.008	$HCOOCH_3$	unassigned[c]	0.040	4.27
102503.656	$HCOOCH_3$	unassigned[c]	0.037	4.43
102531.148	CH_3CCH	6(3)–5(3)	0.122	3.42
102541.336	CH_3CCH	6(2)–5(2)	0.241	4.54
102547.125	CH_3CCH	6(1)–5(1)/6(0)–5(0)[b]	0.589	10.29
102555.430	U[a]		0.084	2.67
102562.609	U[a]		0.061	2.75
102658.531	CH_3OH	11(–2)–11(1) E	0.180	7.16
102958.320	CH_3OH	unassigned	0.163	4.57
W51M				
88864.977	$H^{15}NC$	1–0	0.054	8.52
88904.836	I [CH_3OH	7(2)–6(3) A^-]	0.040	4.98
88939.125	CH_3OH	15(3)–14(4) A^-	0.265	8.79
89059.461	Ua		0.035	3.40
89064.672	U[a]		0.039	2.92
89085.523	HCN	1–0 l=0 F=1–1 ν_2=2	0.065	4.32
89188.438	HCO^+	1–0	7.057	10.67
89296.523	CH_3CH_2CN	10(2,9)–9(2,8)	0.080	6.17
89314.180	$HCOOCH_3$	8(1,8)–7(1,7) A+E[b]	0.215	3.58
89329.773	$^{13}CH_3CN$	5(1)–4(1)/5(0)–4(0)[b]	0.047	8.06
89426.820	I [SO	2(2)–1(1)]	0.072	5.72
89465.852	I [$HC^{15}N$	1–0]	0.048	5.00
89504.766	CH_3OH	8(–4)–9(–3) E	0.340	9.39
102488.734	$HCOOCH_3$	unassigned[c]	0.077	7.02
102502.125	$HCOOCH_3$	unassigned[c]	0.071	4.21
102515.898	CH_3CCH[a]	6(4)–5(4)	0.051	2.83
102529.133	CH_3CCH	6(3)–5(3)	0.235	6.00
102538.820	CH_3CCH	6(2)–5(2)	0.299	5.84
102546.750	CH_3CCH	6(1)–5(1)/6(0)–5(0)[c]	0.750	11.12
102554.047	U[a]		0.053	4.47

Table V

(Continued.)

Source Frequency (MHz)	Molecule	Transition	T_a^* (K)	Δv (km s^{-1})
102560.594	U[a]		0.071	7.67
102587.164	U[a]		0.055	5.60
102657.266	CH_3OH	11(−2)–11(1) E	0.240	8.58
102733.688	$HCOOCH_3$	16(5,11)–16(4,12) A+E[b]	0.059	2.44
102805.992	$H_2C^{34}S$	3(1,2)–2(1,1)	0.088	6.22
102956.797	CH_3OH	unassigned	0.169	8.98
NGC 7538				
89188.047	HCO^+	1–0	4.621	4.31
102545.289	CH_3CCH	6(1)–5(1)/6(0)–5(0)[b]	0.152	5.60
102770.984	U[a]		0.070	2.65
102785.859	U[a]		0.536	2.63

Notes: spectral features not attributable to any known molecular transition are denoted U; features arising from the image sideband are denoted I; T_a^* is antenna temperature and Δv is line width; observed frequency calculated using VLSR given in Table II.

[a] This is the first interstellar detection of this transition.

[b] Possible blend of two transitions.

[c] From the laboratory work of Prof. S. Tsunekawa, Toyama University, Japan.

? Tentative assignment.

the HCO^+ (J=1–0) detection at 89179 MHz in SgrB2 is a complex mixture of emission and absorption features, such that the line intensity and line width could not be determined well.

Conclusions

We have measured upper limits to the column density and fractional abundance of oxiranecarbonitrile (C_3H_3NO) and determined that its fractional abundance in several interstellar molecular clouds is significantly less than that of species such as CH_3CH_2CN (ethyl cyanide), $HCOOCH_3$ (methyl formate), and cyclic C_3H_2 (cyclopropenylidene). Since C_3H_3NO has not been included in published models of interstellar chemistry, it is not yet possible to use this limit to evaluate features of such models. Hopefully, these new data will provide such a constraint on future models. Before pursuing an astronomical search for C_3H_3NO to even lower levels, it may be useful to search for the structurally related but simpler species ethylene oxide (H_2COCH_2); such observations are planned.

In regard to the significance of our abundance limit for origin of life studies, we reiterate the potentially key role for oxiranecarbonitrile in prebiotic chemistry. Like other highly strained cyclic molecules, it has a high reactivity in oligomerization and esterification processes. Particularly important in this context is phosphorylation.

We note the experimentally verified transformation of C_3H_3NO in aqueous solution to glycolaldehyde nitrile, in the presence of formaldehyde to glycolaldehyde, and in the presence of esterifiable anions, such as phosphate, to glycolaldehyde phosphate, which is considered a crucial initiator for condensation reactions to the sugar phosphates that form the backbone of RNA and potential precursor forms such as p-RNA (Pitsch *et al.*, 1994). Moreover, this condensation reaction has been demonstrated to take place at high yield under rather naturally occurring circumstances (Pitsch *et al.*, 1995). If C_3H_3NO were astrophysically important, for example in interstellar or cometary chemistry, it would consequently provide an appealing metaphor for the first link in the chain of reactions leading to p-RNA. Although we have not detected C_3H_3NO in the gas phase in the molecular clouds searched, there remains the possibility that it may be present in interstellar grain mantles and hence in comets. We note the apparent presence of another strained ring compound, $C_3H_3^+$, in cometary comae (Huebner *et al.*, 1991), and we suggest that evidence for C_3H_3NO be sought in both comets and in laboratory experiments which simulate the production of organic components in icy grain mantles. We accordingly hope that this paper has pointed to some important problems in biopoesis and suggested directions for future research.

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