

11

Molecular Cloud Comparisons

11.1 Molecular abundances relative to HCO^+

To aid comparison with local molecular clouds, I have derived molecular abundances relative to that of HCO^+ for EC2 (position A) and EC1 (position T), assuming that the 1–0 transition is optically thin. For EC2 my upper limit to H^{13}CO^+ gives a lower limit to $\text{HCO}^+/\text{H}^{13}\text{CO}^+$ of around 17, much less than the lower limit of 201 ± 15 derived from CO 1–0 by Wouterloot and Brand (1996) towards WB 89-437 at a galactocentric distance of 16.4 kpc, although I note that the value they derive from the 2–1 transition is much smaller, 104 ± 60 .

Table 11.1 shows the results for both EC2 and EC1, and also the equivalent abundance ratios for the nearby dark clouds L134N (centre position), TMC-1 (average) and the range of values derived in L134N (Dickens et al. 2000; Pratap et al. 1997). Note that these authors use isotopic species to determine the column densities of optically thick lines. In particular, they adopt $^{12}\text{C}/^{13}\text{C} = 64$ for determining the column densities of HCO^+ , HCN and HNC and $^{16}\text{O}/^{18}\text{O} = 500$ to determine the CO and ^{13}CO column densities. Finally I note that they used a dipole moment of 4.07 D for HCO^+ compared to the value of 3.9 D used here. Use of my value would increase their abundance ratios by about 10 per cent.

11.2 Molecular abundances relative to H₂

Table 11.2 lists molecular abundances ratios relative to H₂ for EC2 (position A), EC1 (position T), and Trans (translucent cloud observations by Turner 2000). Optically thin emission is assumed for all molecules, with no isotopic ratio corrections. For EC2 and EC1 $T_{\text{ex}} = 20$ K, $N(\text{H}_2) = 7.4 \times 10^{22} \text{ cm}^{-2}$, with $n(\text{H}_2) = 1.2 \times 10^4 \text{ cm}^{-3}$ assumed in calculation of the fractional abundances.

11.3 Comparison with local molecular clouds

The data in Table 11.1 indicates some interesting differences between EC2, EC1 and local molecular clouds. In particular sulphur-bearing molecules, (CS and SO), appear to be very over-abundant in both edge clouds; the nitrogen-bearing species HCN is comparable in EC2, but under-abundant in EC1, whereas HNC is under-abundant in both clouds; and the radicals CN and C₂H are very much over-abundant in EC2. The latter result is typical of photon-dominated regions in which photons ensure that radicals exist in high abundance. At first glance it would appear that the molecular clouds at the edge of the Galaxy would be less likely to show the effects of PDR chemistry; certainly the flux of UV photons must be much less at large Galactocentric distances than in the local ISM. However, the critical parameter for determining whether or not photons dominate chemistry is the ratio of UV flux to grain surface area, particularly the area of the small grains which extinguish UV photons most efficiently. At large Galactocentric radii, the metal abundances relative to hydrogen are expected to be much reduced as discussed in section 8.2. In addition, although the region of EC2 does contain young stars (de Geus et al. 1993), there is no evidence of the late-type stars which produce dust grains.

11.4 Comparison with translucent clouds

Table 11.2 compares abundance ratios relative to H_2 for EC2 and EC1 with those for translucent cloud observations by Turner (2000), and both edge clouds are seen to be under-abundant by at least 2 orders of magnitude for the molecules detected by Turner. As I have measured $N(X)$, the only way to have fractional abundances for EC2 and EC1 similar to local clouds, would be to insist that $N(H_2)$ is 100 times smaller, i.e. 7×10^{20} , which would give cloud sizes of roughly 0.02 pc, which is clearly not at all consistent with my CO maps. So, although $N(H_2)$ may not be known precisely, especially for EC1 where I have chosen a value, it is clear that fractional abundances in edge clouds are less than in local clouds.

11.5 Comparison of EC1 with EC2

From the abundances listed in Tables 11.1 and 11.2, EC1 appears to be a chemically less varied environment compared to EC2. Based on good detections in both clouds, and assuming $N(H_2) = 7.4 \times 10^{22} \text{ cm}^{-2}$, HCO^+ is 3 times less-abundant in EC1, so abundance comparisons relative to HCO^+ give a slightly different picture to those relative to H_2 .

X/HCO^+

For CO and its isotopomers ^{13}CO and $C^{18}O$, abundances are around the same in both clouds. For sulphur-bearing molecules, CS abundances are similar, but SO is ~ 3 times more abundant in EC1. As to the radicals, CN is possibly more abundant in EC1, but C_2H and HCN appear under-abundant by at least a factor of two. The high abundance of SO in EC1 suggests that the cloud is also fairly highly evolved chemically. However, for many molecules in EC1, my non-detections only give upper limits, so firm conclusions as to the state of EC1 can not be established. The closer of the two edge clouds certainly appears to be chemically less interesting.

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Table 11.1: Comparison of molecular abundances ratios relative to HCO⁺ in EC2 (position A), EC1 (position T), L134N (centre), TMC-1 (average) and L134N (range) (Dickens et al. 2000; Pratap et al. 1997). For EC2 and EC1 $T_{\text{ex}} = 20$ K and $N(\text{H}_2) = 7.4 \times 10^{22} \text{ cm}^{-2}$ assumed in calculation of fractional abundances: for EC2 $N(\text{HCO}^+) = 1.45 \times 10^{12} \text{ cm}^{-2}$ so that $X(\text{HCO}^+) = 2.0 \times 10^{-11}$; for EC1 $N(\text{HCO}^+) = 5.00 \times 10^{11} \text{ cm}^{-2}$ so that $X(\text{HCO}^+) = 6.8 \times 10^{-12}$.

X/HCO ⁺		EC2	EC1	L134N	TMC-1	L134N range
CO	1-0	17078	26458	11000 ^b	7800 ^b	
¹³ CO	1-0	2919	3417	172 ^a	122 ^a	111-188
C ¹⁸ O	1-0	214	<245	22.00	15.60	14.2-24
C ¹⁷ O	1-0	<38.8		—	—	
CO	2-1	6070		11000 ^b	7800 ^b	
¹³ CO	2-1	1308		172 ^a	122 ^a	
C ¹⁸ O	2-1	92		22.00	15.60	
CO	3-2	3389		11000 ^b	7800 ^b	
¹³ CO	3-2	439		172 ^a	122 ^a	
C ¹⁸ O	3-2	<27.2		22.00	15.60	
C _I		53020		—	—	
CS	2-1	2.33	2.58	0.124	0.320	0.069-0.138
CS	3-2	0.26		0.124	0.320	
C ³⁴ S	3-2	<0.08		—	—	
CN ^d		1.58	<6.28	0.061	0.070	<0.045-0.069
SO	1-0	13.0		0.719	0.130	0.264-0.738
SO	3-2	2.87	8.04	0.719	0.130	0.264-0.738
DCO ⁺	1-0	<0.08	<0.43	—	—	
H ¹³ CO ⁺	1-0	<0.06		^c	^c	
HCO ⁺	1-0					
DCN	1-0	<1.13	^s <0.95			
H ¹³ CN	1-0	<0.07		^c	^c	
HCN	1-0	0.76	<0.31	0.925	0.490	0.555-0.968
HNC	1-0	0.24	<0.50	3.251	1.680	1.324-3.963
C ₂ H ^e	1-0	35.5	<19.9	0.288	0.300	0.171-0.333
N ₂ H ⁺	1-0	<0.07	<0.33	0.077	0.013	0.031-0.077
H ₂ CO		3.87	^p <13			
NH ₃		4.0	^p <15	7.635	2.770	4.284-9.127
HC ₃ N	9-8	<0.18		0.054	0.150	0.030-0.073
CH ₃ OH	2-1		<1.40	0.641	0.099	0.311-0.641

^a A ¹³CO/C¹⁸O ratio of 7.81 was assumed in L134N and TMC-1.

^b A ¹²CO/C¹⁸O ratio of 500 was assumed in L134N and TMC-1.

^c A ¹²C/¹³C ratio of 64 was assumed in L134N and TMC-1.

^d From the sum of the two 113.49 GHz components assuming a relative intensity for this line of 0.456.

^e From the 87.317 GHz component assuming a relative intensity for this line of 0.4167.

^s EC1 position S. ^p EC1 position P.

Table 11.2: Comparison of molecular abundances ratios relative to H_2 in EC2 (position A), EC1 (position T), and Trans (translucent cloud observations by Turner 2000). For EC2 and EC1 $T_{\text{ex}} = 20$ K, $N(H_2) = 7.4 \times 10^{22} \text{ cm}^{-2}$, with $n(H_2) = 1.2 \times 10^4 \text{ cm}^{-3}$ assumed in calculation of fractional abundances.

X/ H_2		EC2	EC1	Trans
CO	1-0	3.3×10^{-07}	1.8×10^{-07}	
^{13}CO	1-0	5.7×10^{-08}	2.3×10^{-08}	
C^{18}O	1-0	4.2×10^{-09}	$<1.7 \times 10^{-09}$	
C^{17}O	1-0	$<7.6 \times 10^{-10}$		
CO	2-1	1.2×10^{-07}		
^{13}CO	2-1	2.6×10^{-08}		
C^{18}O	2-1	1.8×10^{-09}		
CO	3-2	6.6×10^{-08}		
^{13}CO	3-2	8.6×10^{-09}		
C^{18}O	3-2	$<5.3 \times 10^{-10}$		
Cl		1.0×10^{-06}		
CS	2-1	4.6×10^{-11}	1.7×10^{-11}	1.1×10^{-08}
CS	3-2	5.1×10^{-12}		
C^{34}S	3-2	$<1.5 \times 10^{-12}$		
CN^{d}		3.1×10^{-11}	$<4.2 \times 10^{-11}$	
SO	1-0	2.5×10^{-10}		3.2×10^{-08}
SO	3-2	5.6×10^{-11}	5.4×10^{-11}	
DCO^+	1-0	$<1.6 \times 10^{-12}$	$<2.9 \times 10^{-12}$	
H^{13}CO^+	1-0	$<1.1 \times 10^{-12}$		
HCO^+	1-0	2.0×10^{-11}	6.8×10^{-12}	2×10^{-09}
DCN	1-0	$<2.2 \times 10^{-11}$	$^{\text{s}} <4.2 \times 10^{-12}$	
H^{13}CN	1-0	$<1.4 \times 10^{-12}$		
HCN	1-0	1.5×10^{-11}	$<2.1 \times 10^{-12}$	3.6×10^{-08}
HNC	1-0	4.7×10^{-12}	$<3.4 \times 10^{-12}$	2.5×10^{-09}
$\text{C}_2\text{H}^{\text{e}}$	1-0	7.0×10^{-10}	$<1.3 \times 10^{-10}$	6.6×10^{-08}
N_2H^+	1-0	$<1.3 \times 10^{-12}$	$<2.3 \times 10^{-12}$	$\sim 1 \times 10^{-09}$
H_2CO		7.6×10^{-11}	$^{\text{p}} <9.0 \times 10^{-11}$	6.3×10^{-09}
NH_3		7.8×10^{-11}	$^{\text{p}} <1.0 \times 10^{-10}$	2.1×10^{-08}
HC_3N	9-8	$<3.5 \times 10^{-12}$		5×10^{-10}
CH_3OH	2-1		$<9.5 \times 10^{-12}$	1.8×10^{-08}

^d From the sum of the two 113.49 GHz components assuming a relative intensity for this line of 0.456.

^e From the 87.317 GHz component assuming a relative intensity for this line of 0.4167.

^s EC1 position S. ^p EC1 position P.

X/H₂

Comparisons relative to H₂ present a slightly different picture. As stated above, HCO⁺ is 3 times less-abundant in EC1, and I find CO, ¹³CO and C¹⁸O to be about half as abundant. CS abundances are ~2 times less in EC1, with SO around the same. The upper limits for the radicals give CN about the same abundance, but C₂H is at least 5 times less abundant in EC1. Based on my upper limits, HCN may be much less abundant in EC1, but other molecules are, at most, equally abundant.