Metal-poor molecular gas in Edge Cloud 2

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Introduction

Edge Cloud 2 (EC2) is a molecular cloud at a kinematic galactocentric distance of 28 kpc, some 6 kpc further away than the next most distant molecular cloud, and much further than the extent of the optical disk of the Milky Way, ~ 19 kpc, and almost as far as the most distant H I detected, at ~ 30 kpc. EC2 was found to have an associated H II region excited by an early B star MR1 (de Geus et al. 1993), and Snell et al. (2002) argue that it is the most distant star-forming cloud in the Milky Way, with evidence for massive star formation. Rolleston et al. (2000) have calculated metal depletion for C, N, O ~ 5, and EC2 is the only edge cloud detected in the high-density tracer CS (Digel et al. 1996). We are carrying out an observational study of EC2 to determine physical parameters, chemical abundances and isotopic ratios by developing a chemical kinetic model of metal-poor gas. This will afford us a window to the early Galaxy and to molecular evolution in low metallicity Galactic clouds and extragalactic sources.

Observations

We have observed EC2 in a number of molecular lines using the University of Arizona 12m telescope at 3 and 2mm, and the Effelsberg 100m dish at 1.2, 2 and 6cm. Fig. 1 shows a sample spectrum of HCO^+ 1–0, and Table 1 summarises the University of Arizona 12m detections (and non-detections) to date. Fig. 2 shows Effelsberg spectra of NH_3 and H_2CO from which we derive that the gas temperature is $T_k = 20$ K (from 12 hyperfine lines of NH_3) and the density is $5 \times 10^3 cm^{-3}$ (from four lines of H_2CO).

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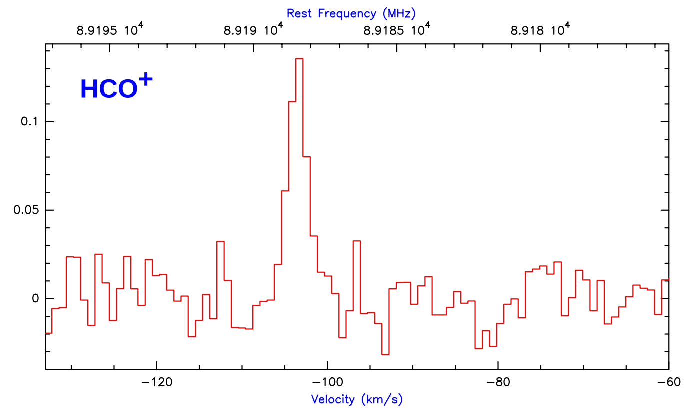

Fig. 1. HCO^+ 1–0 observed in EC2.

Analysis

Table 2 shows derived molecular abundances relative to HCO^+ in EC2, and for comparison those in a local dark cloud L134N. Our observations reinforce the uniqueness of EC2: it has extremely low gas pressure; very small spiral arm perturbation; low metallicity; and similarities to molecular gas in irregular dwarf galaxies such as the Magellanic Clouds. Comparing observed nitrogen bearing molecules in EC2 with L134N, we find N underabundant in EC2.

Table 1. Detections in EC2 at position α_{1950} = 2:44:52.6, δ = 58:16:0.0).

Line	Trans.	Int.(K)	rms (K)	Line	Trans.	Int.(K)	rms (K)
^{13}CO	1–0	0.718	0.065	N_2H^+	1–0	—	0.007
$C^{18}O$	1–0	0.057	0.014	HCO^+	1–0	0.132	0.014
$C^{17}O$	1–0	—	0.007	SO	3_2–2_1	0.057	0.007
CS	2–1	0.125	0.024	HCS^+	2–1	0.032	0.009
CS	3–2	0.043	0.008	C_3H_2	$2_{1,2}$–$1_{0,1}$	—	0.016
$C^{34}S$	3–2	—	0.01	C_2H	1–0	0.073	0.007
CH_3OH	2_0–1_0 A^+	0.019	0.005			0.028	″
	2_{-1}–1_{-1} E	0.025	″	HCN	1–0	0.036	0.013
H_2CO	$2_{1,1}$–$1_{1,0}$	0.037	0.005			0.051	″
$H^{13}CO^+$	1–0	—	0.009	HNC	1–0	0.032	0.007
DCO^+	1–0	—	0.005	H_2CO	$2_{1,2}$–$1_{1,1}$	0.051	0.013
$H^{13}CN$	1–0	—	0.006	CN	$1,\frac{3}{2},\frac{5}{2}$–$0,\frac{1}{2},\frac{3}{2}$	0.021	0.004
HC_3N	9–8	—	0.007		$1,\frac{3}{2},\frac{3}{2}$–$0,\frac{1}{2},\frac{1}{2}$	0.016	″

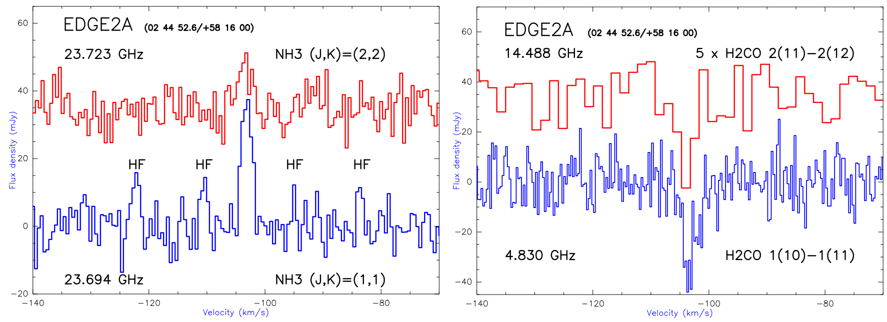

Fig. 2. (a) NH_3 (J,K) = (2,2) and (1,1) observed in EC2 (HF = group of satellite hyperfine components). **(b)** H_2CO 2(11)–2(12) & 1(10)–1(11) observed in EC2.

Modelling

In parallel with our observations we are developing chemical kinetic models for EC2, including the effects of low metallicity and deuterium chemistry. A comparison between observations and a low metallicity model is given in Table 2, together with initial fractional abundances. Comparing observed nitrogen bearing molecules in EC2 with our model, we find that there needs to be an additional decrease of N in the model by a factor of ~ 2 to obtain a clear agreement with observations. Compared to 'local' clouds such as L134N (Dickens et al. 2000), N in EC2 is thus underabundant by a factor of ~ 10. Fig. 3 shows a plot of fractional abundances of some species versus time using different parameters to those of the low metallicity model in Table 2, but the same elemental abundances. Since this shows that DCN/HCN and HCN, etc. vary with time, we also need to investigate the 'early time' behaviour of our models to determine the age of EC2.

Table 2. (a) Steady-state molecular abundance ratios for a low metallicity model compared to EC2 and L134N (Dickens et al. 2000). Model parameters: T = 10 K; $n(H_2) = 10^4\,cm^{-3}$; CRI = $1.3\times10^{-17}\,s^{-1}$. **(b)** Initial fractional abundances, relative to total hydrogen density (also used for model depicted in Fig. 3).

X/HCO^+	EC2	Low metallicity	L134N
CS	0.692	0.392	0.124
SO	1.040	0.594	0.719
CH_3OH	0.309	0.002	0.641
C_2H	14.900	0.318	0.288
CN	0.600	2.225	0.061
HCN	0.506	0.715	0.925
HNC	0.212	0.873	3.250
HC_3N	< 0.029	0.026	0.054
N_2H^+	< 0.024	0.035	0.077
NH_3	3.010	6.789	7.630

Species	Abundances
H_2	5.00×10^{-1}
He	1.40×10^{-1}
C^+	1.46×10^{-5}
N	2.69×10^{-6}
O	3.51×10^{-5}
Si^+	3.99×10^{-9}
Fe^+	1.99×10^{-9}
S^+	2.00×10^{-8}
HD	1.60×10^{-5}

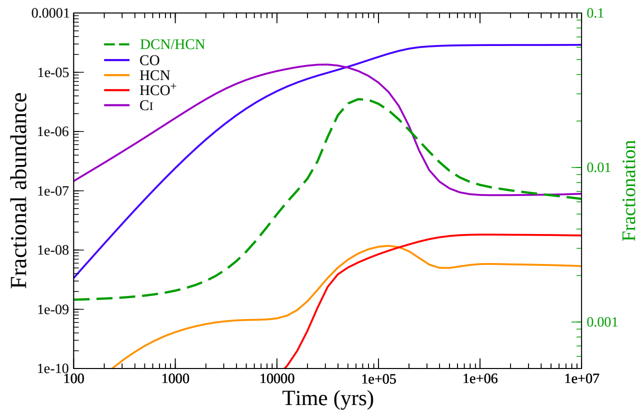

Fig. 3. Fractional abundance model for CO, HCN, HCO^+ and C I compared to DCN/HCN with $T = 20$ K; $n(H_2) = 5 \times 10^3$ cm^{-3}; CRI rate = 1.3×10^{-17} s^{-1}; D/H = 4×10^{-5} using the elemental abundances listed in Table 2.

Future work

We are extending our observations to additional transitions at higher frequency, to better trace the dense gas associated with star formation, and to constrain molecular and elemental abundances, density, temperature, and column densities. In this context, observations of the C I line at 492 GHz will be very valuable in constraining, with CO, the total elemental abundance of carbon, and therefore give additional information on how good the CO/H_2 ratio can trace mass at low metallicities (Walter et al. 2003). Fig. 3 shows that C I is more abundant than CO up to 10^5 years in the model. Likewise, better constraints on the HCO^+ abundance can be linked to the cosmic ray ionisation (CRI) rate and electron fractionation. We shall also be able to compare our results (both elemental and molecular abundances) with those in other dwarf galaxies, particularly the Magellanic Clouds (Chin et al. 1996, 1997, 1998). Assuming that EC2 is comparable to the Magellanic Clouds, its closer proximity, by a factor of 2-3, offers an ideal opportunity to study metal-poor molecular gas in greater detail.

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