Detection of Negative Ions toward a Low-Mass Protostar, L1527

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(Sakai et al. 2007a, ApJ, 667, L65)

Abstract

We have detected the J = 7－6 (19.3 GHz), 8－7 (22.0 GHz), and 15－14 (41.3 GHz) lines of C_6H^- toward a low-mass star-forming region of L1527 with GBT and Nobeyama 45 m telescope. We have also detected the J = 15/2－13/2 and 33/2－31/2 lines of the corresponding neutral species, C_6H, and the $8_{1,8}－7_{1,7}$ line of C_6H_2 in L1527. This is the first detection of these three species in star forming regions.

The intensities of the J = 7－6, 8－7, and 15－14 lines of C_6H^- are 14, 26, and 26 mK (T_{MB}), respectively. The column density of C_6H^- is (5.8±1.8) $\times 10^{10}$ cm^{-2}, which is comparable to that in TMC-1, although the column density of C_6H in L1527 is about 1/5 of that in TMC-1. Thus the [C_6H^-]/[C_6H] ratio is evaluated to be 0.093±0.029, being higher than that in TMC-1 by a factor of 4. The high [C_6H^-]/[C_6H] ratio is discussed in terms of the simplified chemical model. The present result demonstrates importance of the anion chemistry in a dense part of the star forming region. The chemical simulation of the [C_6H^-]/[C_6H] ratio in the gravitationally contracting cloud would be interesting.

Background

Interstellar Clouds ・・・・ Low Ionization Plasma

$f \sim 10^{-4}$ for diffuse clouds

$f \sim 10^{-8}$ for dense clouds

★Positive Charge : H_3^+, HCO^+, He^+, H^+, etc.

★Negative Charge : electron, negatively charged dust (including PAH), molecular anion

NOT DETECTED !

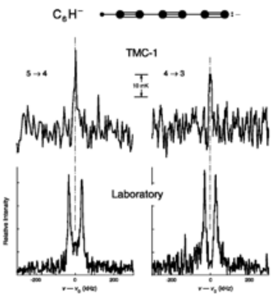
①The best candidates of molecular anion are carbon-chains

$C_{2n}H$ series	$C_{2n}H^-$ series	Electron Affinity:
CCH (C_2H)	CCH^- (C_2H^-)	EA = 2.97 eV
CCCCH (C_4H)	$CCCCH^-$ (C_4H^-)	EA = 3.56 eV
CCCCCCH (C_6H)	$CCCCCCH^-$ (C_6H^-)	EA = 3.81 eV
CCCCCCCCH (C_8H)	$CCCCCCCCH^-$ (C_8H^-)	EA = 3.97 eV

cf. CS : EA = 0.21 eV
CO : EA < 0 eV
H_2O : EA < 0 eV

Large electron affinity & Abundant in cold dark clouds

②First detection of carbon-chain anions in the laboratory & interstellar clouds



(McCarthy, M. C. et al. 2006)

C_6H^-
★TMC-1: Cold Starless Core
★IRC+10216: Evolved Star
(McCarthy, M. C. et al. 2006)

C_8H^-
★TMC-1 (Brüenken, S. et al. 2007)
★IRC+10216 (Remijan, A. et al. 2007)

C_4H^-
★IRC+10216 (Cernicharo, P. et al. 2007)

L1527

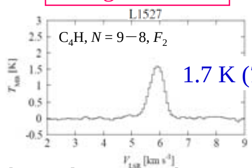
③Exceptionally carbon-chain-rich protostar, IRAS 04368+2557 in L1527

We have found that various carbon-chains exist in a *dense* and *warm* part of the star-forming region.

ex. C_4H, C_4H_2, C_5H, C_6H, C_6H_2, HC_7N, HC_9N, CH_3CCH, etc.

Long Carbon-Chains !

Strong Emission !



(Sakai et al. ApJ, 2007b, in press.)

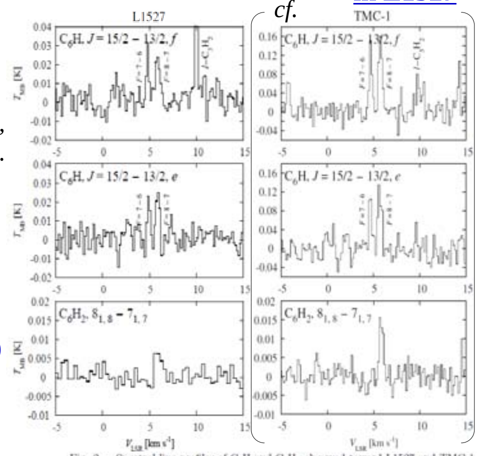
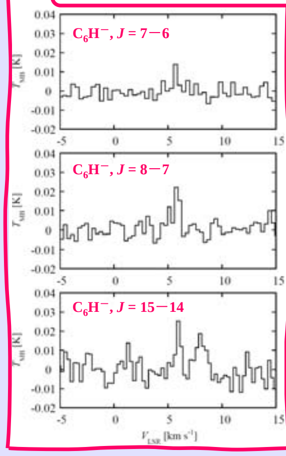


Fig. 2.— Spectral line profiles of C_6H and C_6H_2 observed toward L1527 and TMC-1.

Detection of C_6H^- in L1527



④Column density of C_6H^-: TMC-1 vs. L1527

		TMC-1	L1527
C_6H^-	T_{rot}	～ 5 K *	9.5 K
	N	1 × 10^{11} cm^{-2} *	0.6 × 10^{11} cm^{-2}
C_6H	T_{rot}	6.1 K	12.0 K
	N	3 × 10^{12} cm^{-2}	0.6 × 10^{12} cm^{-2}
[C_6H^-]/[C_6H]		2.5 % *	**9.3 %**

(* Taken from McCarthy et al. 2006)

[C_6H]/[C_6H^-] is much higher than that in TMC-1 !

Origin of high [C_6H^-]/[C_6H] ratio

⑤Formation pathways

1) radiative attachment

C_6H + e → C_6H^- + $h\nu$

2) dissociative attachment

C_6H_2 + e → C_6H^- + H (+ 16 kJ/mol)
(hexapentaenylidene)

cf; C_nH_2 + e → C_nH^- + H (＋47 kJ/mol @ n=8) (cumulene) (－26 kJ/mol @ n=4)

⑥Destruction pathways

3) associative detachment

C_6H^- + H → C_6H_2 + e (+ 158 kJ/mol)
(triacetylene)

4) neutralization

C_6H^- + M^+ → C_6H + M

5) electron transfer, etc.

C_6H^- + G → C_6H + G^-
→ products

⑦Why [C_6H^-] /[C_6H] is higher for L1527 ?

$$\frac{[C_6H^-]}{[C_6H]} = \frac{[e](k_1 + k_2[C_6H_2]/[C_6H])}{(k_3[H] + k_4[M^+] + k_5[G])} = \frac{k_{eff}[e]}{(k_3[H] + k_4[M^+] + k_5[G])}$$

Assuming $[M^+] = [e]$ and $[H] = 1/[H_2]$,

For n ≤ 10^6 cm^{-3} :Associative detachment 3) is effective

$$\frac{[C_6H^-]}{[C_6H]} \sim \frac{k_{eff}[e]}{k_3[H]}$$ ・・・ TMC-1 case (n ~ 10^4 cm^{-3})

For n ≥ 10^6 cm^{-3} :Neutralization 4) is effective

$$\frac{[C_6H^-]}{[C_6H]} \sim \frac{k_{eff}}{k_4}$$ ・・・ L1527 case (n ≥ 10^6 cm^{-3})

Because of $[H] = 1/[H_2]$, associative detachment 3) becomes less important in higher density condition !

⇒ L1527 : low destruction rate !

Radiative Recombination

M^+ + e → M + $h\nu$ slow (～10^{-12} cm^3 s^{-1})

Neutralization

M^+ + G^- → M + G fast (～10^{-7} cm^3 s^{-1})

Abundant G^- ⇒ Low Ionization Degree ??

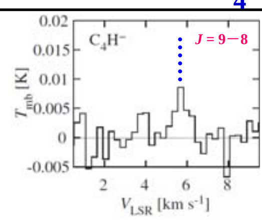
We should know the total abundance of molecular anions in star forming region ! (C_nH^-, C_nN^- etc.)

～ OBSERVATION ～

(http://www.nro.nao.ac.jp/~nro45mrt/NEW45M/IMG/IMGEN/iau_45m.html)

(http://www.gb.nrao.edu)

Detection of C_4H^-



First detection of C_4H^- for a molecular cloud!

[C_4H^-] /[C_4H] : 6.8×10^{-3} %

(Sakai et al. 2007, ApJ, submitted)

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