Abundant Carbon-Chain Molecules toward a Low-Mass Protostar IRAS04368+2557 in L1527

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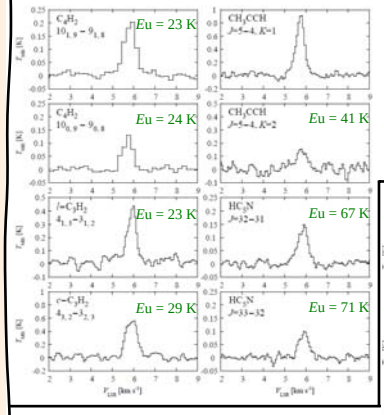
Abstract

We have detected the high excitation lines of carbon-chain molecules such as C_4H_2 ($J = 10_{0,10}-9_{0,9}$, $E_u = 24$ K), C_4H ($N = 9-8$, F_2, $E_u = 21$ K), l-C_3H_2 ($4_{1,3}-3_{1,2}$, $E_u = 23$ K), and CH_3CCH ($J = 5-4$, $K = 2$, $E_u = 41$ K) toward a low-mass star forming region, L1527. In particular, the F_2 line of C_4H is as strong as 1.7 K in T_{MB}. The rotation temperature of C_4H_2 is determined by the multi-transition observation to be 12.3 ± 0.8 K, which is significantly higher than that in TMC-1. Furthermore, the column density of C_4H_2 is derived to be about 1/4 of that in TMC-1, indicating that carbon-chain molecules are abundant in L1527 for a star forming region. Small mapping observations show that the C_4H, C_4H_2 and c-C_3H_2 emissions are distributed from the outer envelope to the inner part of the protostellar disk. In addition, we have detected the lines of C_5H, HC_5N, HC_7N, and HC_9N in the 20 GHz region. Since the carbon-chain molecules are thought to be generally deficient in star forming cores, the above results cannot simply be explained by the existing chemical models. If the timescale of the prestellar collapse in L1527 is shorter than those of the other star forming cores, the carbon-chain molecules can survive in the central part of the core. In addition, regeneration processes of the carbon-chain molecules due to star formation activities would play an important role. Evaporation of CH_4 from the grain mantles would drive the regeneration processes. This is new chemistry in a warm and dense region near the protostars, which is named "Warm Carbon-Chain Chemistry (WCCC)".

Various Carbon-Chains

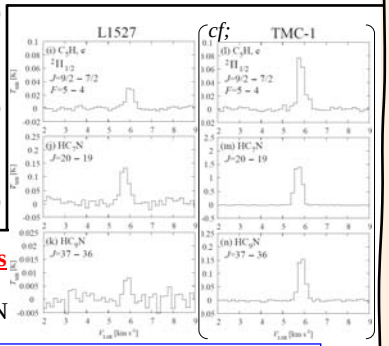
L1527 in *Taurus*: low-mass protostar (Class 0 to Class I)

①Detection of high excitation lines of carbon-chains



ex; C_4H_2, $10_{0,9}-9_{0,8}$
critical density ~ 10^6 cm^{-3}

Such high excitation lines have never been detected toward TMC-1



②Detection of long carbon-chains

C_5H, C_6H, C_6H_2, C_6H^-, HC_7N, HC_9N

Various carbon-chain molecules in a dense and warm part of a star-forming region have not been recognized so far !

Excitation Analysis

③Multi-transition observations of C_4H_2 and CH_3CCH

Dense !

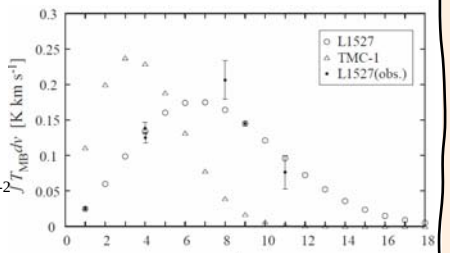
L1527; $T_{rot} = 12.3\pm0.8$ K
TMC-1; $T_{rot} = 3.8\pm0.5$ K

Abundant !

L1527; $N = (1.6\pm0.1)\times10^{12}$ cm^{-2}
TMC-1; $N = (7.1\pm2.6)\times10^{12}$ cm^{-2}

Warm !

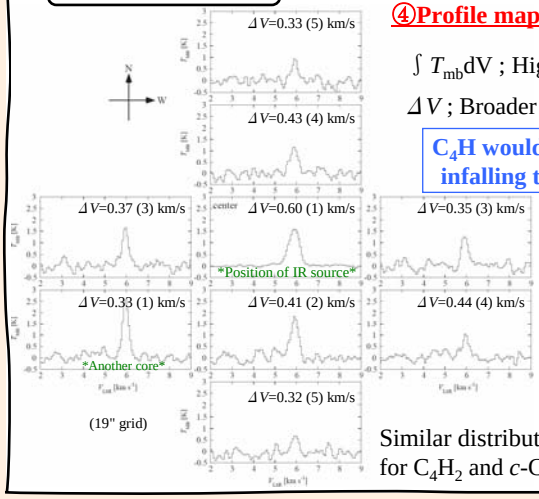
T_K ~ 13.9 K
(CH_3CCH, K=1, 2)



Rotation Diagram of C_4H_2

Distribution

④Profile map of C_4H ($N = 9-8$, F_2)

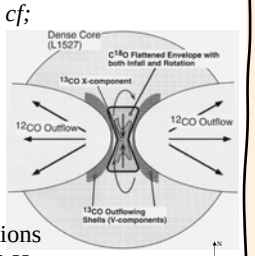


$\int T_{mb}dV$; Highest at the center

ΔV ; Broader toward the center

C_4H would exist in the gas infalling to the protostar

cf;



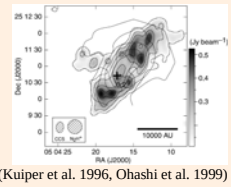
Similar distributions for C_4H_2 and c-C_3H_2

(Ohashi et al. 1997)

⑤Chemical behavior of carbon-chain molecules

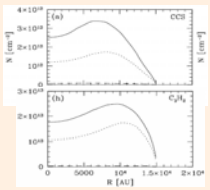
1. Observational result

Doughnut-like distribution of CCS in L1544



(Kuiper et al. 1996, Ohashi et al. 1999)

2. Chemical model simulation (Aikawa et al. 2001)



ex. Column density of CCS

L1527 ; $N = 0.5\times10^{13}$ cm^{-2}
TMC-1; $N = 6.6\times10^{13}$ cm^{-2}
(Hirota et al. 2001)

↑ Certainly!

Carbon-chain molecules are thought to be deficient in star forming cores.

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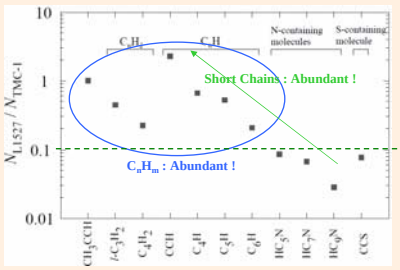
Why are C_nH, C_nH_2, etc. so abundant in L1527 ?

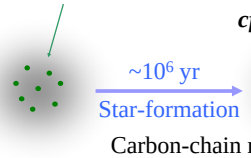


Origin of Abundant Carbon-Chains in L1527

⑥Time Scale of the Prestellar Collapse

ex. CCS, CCH, H_2CCCC, HCCCCCN, etc. ....

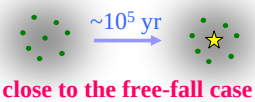
cf; **NGC1333IRAS4B**
IRAS16293−2422



Carbon-chain molecules are deficient.
(e.g. Sakai et al. 2007, van Dishoeck et al. 1995)

Starless core

L1527



Some carbon-chain molecules could survive even in the central part.

close to the free-fall case ?

If so,
we can learn a timescale of the protostellar collapse ??

⑦Warm Carbon-Chain Chemistry (WCCC)

Evaporation of CH_4 would also contribute to the regeneration of carbon-chain molecules.

Regeneration of C_nH_m (Sakai et al. 2007, ApJ, in press; Aikawa et al. 2007, ApJ, in press)

$CH_4 + C^+ \rightarrow C_2H_3^+ + H$

$C_2H_3^+ + e \rightarrow$ $C_2H_2 + H$, $C_2H + H + H$

$C_2H_2 + C^+ \rightarrow$ $C_3H^+ + H$

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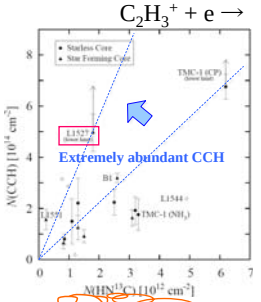
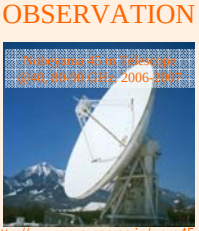


CH_4 in grain mantle:

- Low sublimation temperature ~30 K
- Substantial amount (typically a few % of H_2O ice)

Detailed distribution is the KEY !

~ OBSERVATION ~



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

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