

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

Nami Sakai<sup>1</sup>, Takeshi Sakai<sup>2</sup>, Tomoya Hirota<sup>3</sup>, and Satoshi Yamamoto<sup>1</sup>

(<sup>1</sup>Dept. of Physics, The Univ. of Tokyo, <sup>2</sup>Nobeyama Radio Observatory, <sup>3</sup>National Radio Observatory of Japan) (Sakai et al. 2008, ApJ, 672, 371)

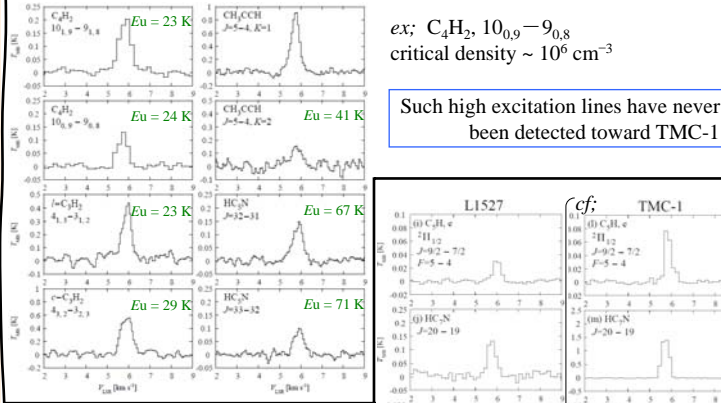
## Abstract

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  $12.3 \pm 0.8$  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  $C_3H$ ,  $HC_5N$ ,  $HC_7N$ , 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)

### ① Detection of high excitation lines of carbon-chains



### ② Detection of long carbon-chains

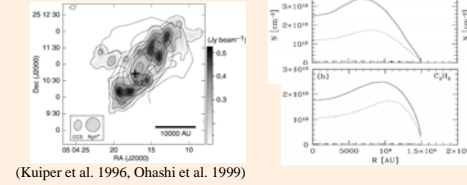
$C_3H$ ,  $C_6H$ ,  $C_6H_2$ ,  $C_6H^-$ ,  $HC_7N$ ,  $HC_9N$

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

### ⑤ Chemical behavior of carbon-chain molecules

1. Observational result 2. Chemical model simulation (Aikawa et al. 2001)

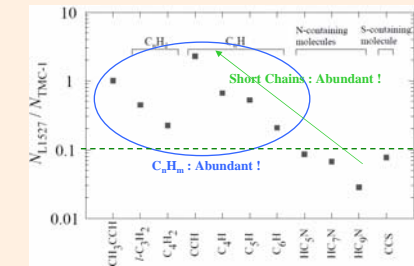
Doughnut-like distribution of CCS in L1544



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

Contact: Nami Sakai, e-mail: nami@taurus.phys.s.u-tokyo.ac.jp

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



~ OBSERVATION ~



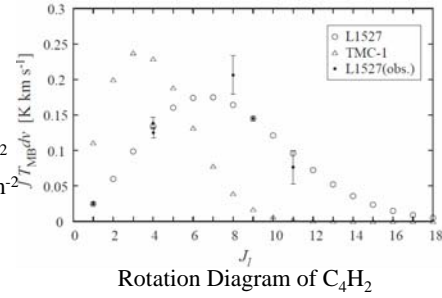
## Excitation Analysis

### ③ Multi-transition observations of $C_4H_2$ and $CH_3CCH$

Dense!  
L1527;  $T_{rot} = 12.3 \pm 0.8$  K  
TMC-1;  $T_{rot} = 3.8 \pm 0.5$  K

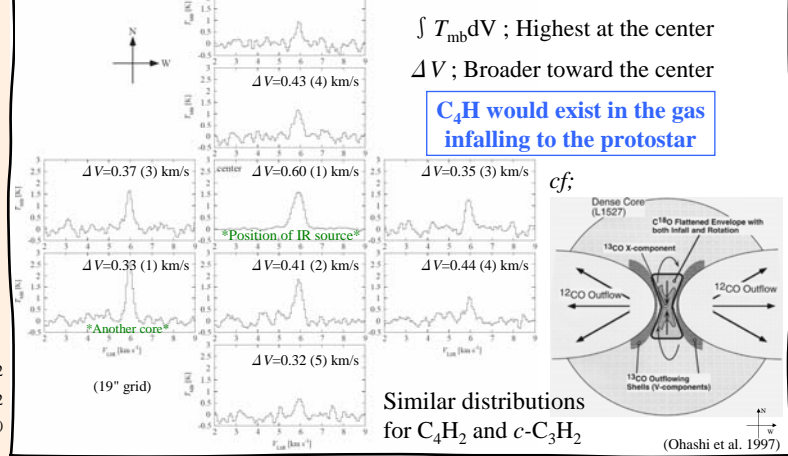
Abundant!  
L1527;  $N = (1.6 \pm 0.1) \times 10^{12}$  cm<sup>-2</sup>  
TMC-1;  $N = (7.1 \pm 2.6) \times 10^{12}$  cm<sup>-2</sup>

Warm!  
 $T_K \sim 13.9$  K  
( $CH_3CCH$ ,  $K=1, 2$ )



## Distribution

### ④ Profile map of $C_4H$ ( $N = 9 - 8, F_2$ )

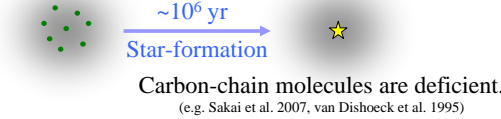


## Origin of Abundant Carbon-Chains in L1527

### ⑥ Time Scale of the Prestellar Collapse

ex. CCS, CCH, H<sub>3</sub>CCCC, HCCCCCN, etc. ....

cf; NGC1333IRAS4B IRAS16293-2422

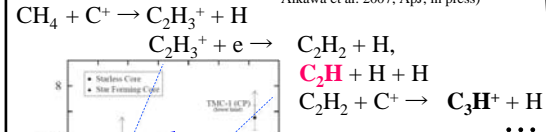


If so, we can learn a timescale of the protostellar collapse ??

### ⑦ Warm 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)



$CH_4$  in grain mantle:  
• Low sublimation temperature  $\sim 30$  K  
• Substantial amount (typically a few % of  $H_2O$  ice)

Detailed distribution is the KEY!