### Various Carbon-Chains

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

1. **Detection of high excitation lines of carbon-chains**
   - ex: C$_4$H$_2$, 10$_{20}$ - 9$_{19}$: critical density $\sim 10^6$ cm$^{-3}$
   - Such high excitation lines have never been detected toward TMC-1

2. **Detection of long carbon-chains**
   - C$_4$H, C$_5$H, C$_5$H$_2$, C$_6$H$_2$, C$_6$H
   - Various carbon-chain molecules in a dense and warm part of a star-forming region have not been recognized so far!

3. **Chemical behavior of carbon-chain molecules**
   - **Observational result**
     - Column density of CCS L1527: $N = 0.5 \times 10^{13}$ cm$^{-2}$
     - TMC-1: $N = 6.6 \times 10^{13}$ cm$^{-2}$
   - **Chemical model simulation**
     - Ex: Column density of CCS

### Excitation Analysis

**Multi-transition observations of C$_4$H$_2$ and CH$_2$CCH**

- **L1527: $T_{mb}$ = 12.3 $\pm$ 0.8 K**
- **TMC-1: $T_{mb}$ = 3.8 $\pm$ 0.5 K**

**WARM**

- $T_K$ = 13.9 K
- (CH$_3$CCH, $K$=1, 2)

**Dense**

- $N$ = (1.6 $\pm$ 0.1) x 10$^{12}$ cm$^{-2}$
- TMC-1: $N$ = (7.1 $\pm$ 2.6) x 10$^{12}$ cm$^{-2}$

### Distribution

- **Profile map of C$_4$H ($N = 9-8$, $E_2$)**
  - $T_{mb}$ = 4 V
  - Highest at the center
  - $\Delta P$; Broader toward the center
- **C$_4$H would exist in the gas infalling to the protostar**

### Origin of Abundant Carbon-Chains in L1527

**Time Scale of the Prestellar Collapse**

- **~30 yr**
  - Carbon-chain molecules are deficient.
  - (e.g. Sakai et al. 2007, van Dishoeck et al. 1995)

**Warm Carbon-Chain Chemistry (WCCC)**

- **Evaporation of CH$_4$ would also contribute to the regeneration of carbon-chain molecules.**
- **Regeneration of C$_4$H$_2$**
  - $\text{CH}_4 + \text{C}^+ \rightarrow \text{CH}_3 + \text{H}$
  - $\text{C}_2\text{H}_2 + \text{e} \rightarrow \text{C}_2\text{H}_3 + \text{H}$
  - $\text{C}_2\text{H}_2 + \text{C}^+ \rightarrow \text{C}_2\text{H}_3 + \text{H}$
  - $\text{C}_2\text{H}_3 + \text{H} \rightarrow \text{C}_2\text{H}_4$
  - $\text{C}_2\text{H}_4 + \text{H} \rightarrow \text{C}_2\text{H}_5$

- **CH$_4$ in grain mantle:**
  - Low sublimation temperature $\sim$30 K
  - Substantial amount
    - (typically a few % of H$_2$O ice)

### 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$_4$H$_2$ ($J = 10_{20} - 9_{19}$, $E_u = 24$ K), C$_4$H ($N = 9 - 8$, $F_2$, $E_u = 21$ K), C$_3$H$_2$ ($J = 3_{12} - 2_{11}$, $E_u = 23$ K), and CH$_3$CCH ($J = 5 - 4$, $K = 2$, $E_u = 41$ K) toward a low-mass star forming region, L1527. In particular, the $F_2$ line of C$_4$H is as strong as 1.7 K in $T_{mb}$. The rotation temperature of C$_3$H$_2$ 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$_4$H$_2$ 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$_4$H, C$_3$H$_2$, and C$_3$H$_2$ emissions are distributed from the outer envelope to the inner part of the protostellar disk. In addition, we have detected the lines of C$_4$H, HC$_5$N, HC$_7$N, and HC$_9$N 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).”