Formation Mechanisms of Cyanopolyynes in Low-Mass Starless Cores

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Cyanopolyynes ($HC_{2n+1}N$; n=1, 2, 3, ...) are one of the representative carbon-chain species. Carbon-chain molecules tend to be abundant in low-mass starless cores and deficient in star-forming cores (e.g., [1]). It is important for understanding of the physical conditions and evolution in early low-mass starless cores to reveal formation mechanisms of carbon-chain molecules. However, the formation mechanisms of carbon-chain species are unclear due to shortage of laboratory experimental data.

One method to investigate formation pathways of carbon-chain molecules is ^{13}C isotopic fractionation, i.e., differences in abundance among the ^{13}C isotopologues. At the cyanopolyyne peak in Taurus Molecular Cloud-1 (TMC-1 CP), the ^{13}C isotopic fractionation of HC_3N was derived to be [$H^{13}CCCN$] : [$HC^{13}CCN$] : [$HCC^{13}CN$] = 1.0:1.0:1.4, and the neutral-neutral reaction of “C_2H_2 + CN” was proposed as the main formation pathway of HC_3N [2]. On the other hand, there is no clear difference in abundance among the five ^{13}C isotopologues of HC_5N. From the results, the ion-molecule reactions of “$C_5H_m^+$ + N” followed by the electron recombination reactions were proposed as the main formation mechanism of HC_5N at TMC-1 CP [3].

We carried out observations of the three ^{13}C isotopologues of HC_3N toward two low-mass starless cores, L1521B and L134N, using the J=5–4 rotational lines in the 45 GHz band with the Z45 receiver installed on the Nobeyama 45-m radio telescope [4]. The abundance ratios of the three ^{13}C isotopologues were derived to be [$H^{13}CCCN$] : [$HC^{13}CCN$] : [$HCC^{13}CN$] = 0.98 (±0.14) : 1.00 : 1.52 (±0.16) and 1.5 (±0.2) : 1.0 : 2.1 (±0.4) (1σ) in L1521B and L134N, respectively. From the ^{13}C isotopic fractionation patterns, the reactions of “C_2H_2 + CN” and “CCH + HNC” were proposed as the main formation pathways of HC_3N in L1521B and L134N, respectively. Figure 1 shows the summary of the main formation pathways of HC_3N in low-mass starless cores. Although these three sources have similar physical conditions ($T \sim 10$ K, $n \sim 10^4$–10^5 cm^{-3}), the proposed main formation pathway in L134N is different from those in L1521B and TMC-1. We conducted a chemical network simulation and found that the CN/HNC abundance ratio may be a key factor to produce the difference in the main formation mechanism of HC_3N among the three cold molecular clouds.

We reported the first detection of $HC_5{}^{15}N$ using the J=9–8 rotational line in the 20 GHz band from TMC-1 CP with the Nobeyama 45-m radio telescope [5]. Its column density was derived to be $(1.9 \pm 0.5) \times 10^{11}$ cm^{-2} (1σ). Applying the double isotope method, the $^{14}N/^{15}N$ ratio of HC_5N was calculated at 344 ± 53. Using the previous data taken from [6] and [2], we estimated the $^{14}N/^{15}N$ ratio of HC_3N at 257 ± 54, which is lower than that of HC_5N. The difference in the $^{14}N/^{15}N$ ratio between HC_5N and HC_3N is considered to be produced during their formation. Since there are possible mechanisms that ^{15}N concentrates into CN in cold gas, the lower ratio of HC_3N implies that the main formation pathway involves CN. The higher $^{14}N/^{15}N$ ratio of HC_5N suggests that the main formation mechanism involves nitrogen atoms, because the $^{14}N/^{15}N$ ratio in the local interstellar medium is ~440. In summary, the suggested main formation mechanisms from ^{15}N isotopic fractionation are consistent with those suggested from ^{13}C isotopic fractionation [2,3].

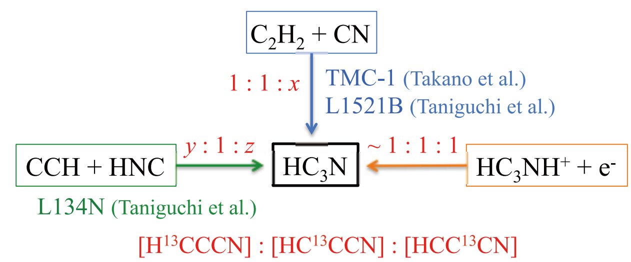

Figure 1: Possible formation mechanisms of HC_3N and the proposed main formation pathways in three cold molecular clouds. Expected ^{13}C isotopic fractionation patterns for each mechanism are shown in red font (discussed in [4] in detail).

References

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