TMRT OBSERVATIONS OF CARBON-CHAIN MOLECULES IN SERPENS SOUTH 1a

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ABSTRACT

We report Shanghai Tian Ma Radio Telescope (TMRT) detections of several long carbon-chain molecules in the C and Ku bands, including HC3N, HC5N, HC7N, HC9N, C3S, C6H, and C8H toward the starless cloud Serpens South 1a. We detected some transitions (HC3N J = 13–12, F = 12–11, and F = 14–13; H13CCCN J = 2–1, F = 1–0, and F = 1–1; HC13CN J = 2–1, F = 2–2, F = 1–0, and F = 1–1; HC3N J = 6–5, F = 5–4; H13CCCN J = 2–1, F = 2–1) for the first time in the interstellar medium. The column densities of these carbon-chain molecules in the range 10^{12}–10^{13} cm^{-2} are comparable to two carbon-chain rich molecules, TMC-1 and Lupus-1A. The abundance ratios are 1.00:(1.11 ± 0.15):(1.47 ± 0.18) for [H13CCCN]/[HC3N]/[HCC13CN]. This result implies that the 13C isotope is also abundant in the carbon atom adjacent to the nitrogen atom in HC3N in Serpens South 1a, which is similar to TMC-1. The [HC3N]/[H13CCCN] ratio of 78 ± 9, the [HC3N]/[HCC13CN] ratio of 70 ± 8, and the [HC3N]/[HCC13CN] ratio of 53 ± 4 are also comparable to those in TMC-1. Serpens South 1a proves to be a suitable testing ground for understanding carbon-chain chemistry.

Key words: ISM: individual objects (Serpens) – ISM: molecules

1. INTRODUCTION

Linear carbon-chain molecules like C2H, HC2n+1N and C3S have been observed to be abundant in cold dense clouds (Bell et al. 1997; Kaifu et al. 2004; Kalenski et al. 2004; Langston & Turner 2007; Sakai et al. 2010), in the circumstellar envelopes of carbon-rich asymptotic giant branch stars (Winnewisser & Walmsley 1978; Cernicharo & Guelin 1996; Guelin et al. 1997; Gong et al. 2015a, 2015b; Watanabe et al. 2015), in photo-dissociation regions (Pety et al. 2005; Gratier et al. 2013), and in diffuse clouds (e.g., Lucas & Liszt 2000; Liszt et al. 2012). The detection of these molecules has revealed that large organic molecules are forming in the interstellar medium (ISM). These species are proposed to be related to the formation and destruction of polyaromatic hydrocarbons (Henning & Salama 1998; Tielens 2008) and may be carriers of some diffuse interstellar bands. These molecules are also considered to be an evolutionary indicator of prestellar cores in star formation studies (Suzuki et al. 1992; Li et al. 2012). The full characterization of carbon-chain molecules is thus regarded as an important issue in astrochemistry (Sakai et al. 2010).

However, studies of long carbon-chain molecules have been seriously limited by the small number of detections. To date, long carbon-chain molecules have primarily been seen toward several nearby, low-mass star-forming regions, and in the envelope of carbon stars (Cernicharo & Guelin 1996; Bell et al. 1997; Guelin et al. 1997; Sakai et al. 2010). For example, HC3N has been detected in two nearby molecular clouds, Taurus (Broten et al. 1978; Sakai et al. 2008) and Lupus (Sakai et al. 2010), while HC11N has only been detected in TMC-1 (Bell et al. 1997). As a consequence, many problems related to the formation and chemistry of carbon-chain molecules remain poorly understood.

The decrease of abundance with increasing chain length is a key parameter for understanding the chemical reaction paths of carbon-chain radicals (Cernicharo & Guelin 1996). A steep drop off in the abundance of long CnH molecules have been seen in IRC +10216; for example, C8H was observed to be a factor of 6–10 less abundant than C6H (Cernicharo & Guelin 1996; Guelin et al. 1997). Bell et al. (1999) also found a steep fall-off in abundance of longer CnH chains in TMC-1, and they concluded that long CnH chains were less likely to be abundant in the diffuse gas. However, C8H was only detected in two molecular clouds, i.e., Lupus-1A (Sakai et al. 2010) and TMC-1 (Bell et al. 1999). It is thus important to observe carbon-chain radicals toward more sources.

Given the astrochemical importance of carbon-chain molecules, their formation mechanism is still a matter of some controversy (e.g., Knight et al. 1986; Winnewisser & Herbst 1987, p. 119), and the study of 13C isotopic fractionation provides a way to discriminate the formation mechanism (Takano et al. 1998; Furuya et al. 2011). Takano et al. (1998) observed the 13C substitutions of HC3N in TMC-1 and found significant differences in abundances among the 13C isotopic species, which differ from those in Sgr B2, Orion KL, and IRC+10216. Based on these results and on the reaction rate coefficients, they concluded that the most important formation reaction of HC3N is probably the reaction between C2H2 and CN. Abundance differences between the 13C isotopologues of CCS, CCH, C3S, and C4H were also found in TMC-1 (Sakai et al. 2007a, 2010a, 2013), and were believed to be caused by different formation processes or 13C isotope exchange reactions. Given that most of these studies are limited to the Taurus molecular cloud, more sources are needed to investigate whether the abundance difference among 13C isotopologues of carbon-chain molecules is general.

Friesen et al. (2013) detected multiple HC3N clumps within the young, cluster-forming Serpens South region in the Aquila rift. Their result extended the known star-forming regions containing significant HC7N emission from typically quiescent
regions, like the Taurus molecular cloud (Kroto et al. 1978), to more complex, active environments. Nakamura et al. (2014) found that CCS is extremely abundant along the main filament in Serpens South, while a high CCS column density is typical of the carbon-chain producing regions suggested by Hirota et al. (2009). Detailed studies of this source will promote our understanding of the formation and destruction mechanisms of long carbon-chain molecules, thus we search for cyanopolyyenes such as HC$_2$N, HC$_7$N, HC$_9$N, hydrocarbons (e.g., C$_2$H and C$_6$H), and other carbon-chain molecules of astrochemical interest with the Shanghai Tian Ma Radio Telescope (TMRT) toward the strongest HC$_7$N emission clump, Serpens South 1a, which lies directly to the north of a filamentary ridge.

2. OBSERVATIONS AND DATA REDUCTION

We performed observations of carbon-chain molecules in the Ku and C bands toward Serpens South 1a in 2015 May with the TMRT. The TMRT is a new 65 m diameter fully steerable radio telescope located in the western suburbs of Shanghai, China (Yan et al. 2015). Five cryogenically cooled receivers covering the frequency ranges 1.25–1.75 GHz (L), 2.2–2.4 GHz (S), 4.0–8.0 GHz (C), 8.2–9.0 GHz (X), and 11.5–18.5 GHz (Ku), are now available. The digital backend system (DIBAS) of TMRT is an FPGA-based spectrometer based on the design of the Versatile GBT Astronomical Spectrometer (Bussa 2012). For molecular line observations, DIBAS supports a variety of observing modes, including 19 single sub-band modes and 10 eight sub-band modes. The bandwidth of the a single sub-band mode varies from 1250 to 11.7 MHz. The spectrometer supports eight fully tunable sub-bands within a 1300 MHz bandwidth. The bandwidth of each sub-band is 23.4 MHz for modes 20–24 and 15.6 MHz for modes 25–29. The center frequency of the sub-band is tunable to an accuracy of 10 KHz.

Figure 1 (upper left panel) shows the HC$_7$N $J = 21–20$ and NH$_3$ integrated intensities observed with the Robert C. Byrd Green Bank Telescope (GBT) overlaid as contours over the thermal continuum emission from dust at a sub-millimeter wavelength (André et al. 2010; Friesen et al. 2013). The 54$^a$ FWHM TMRT beam at 18 GHz (yellow circle) and the 121$^a$ FWHM TMRT beam at 8 GHz (blue circle) are shown. The coordinates adopted for our searches were R.A. (2000) = 18.29:57.9 and decl. (2000) = −1:56:19.0. The pointing accuracy is better than 12$^a$. The DIBAS mode 20 was adopted for Ku band observation, with eight spectral windows, each of which has 4096 channels and a bandwidth of 23.4 MHz, supplying a velocity resolution of about 0.12 km s$^{-1}$ (15 GHz) and 0.09 km s$^{-1}$ (18 GHz) in the Ku band. The DIBAS mode 22 was adopted for C band observation, with eight spectral windows, each of which has 16384 channels and a bandwidth of 23.4 MHz, supplying a velocity resolution of about 0.05 km s$^{-1}$ at 8 GHz. The intensities were calibrated by injecting periodic noise and the accuracy of the intensity calibration is 20%. The system temperatures were calibrated by injecting periodic noise and the accuracy of the intensity calibration is 20%. The system temperatures were calibrated by injecting periodic noise and the accuracy of the intensity calibration is 20%. The system temperatures were calibrated by injecting periodic noise and the accuracy of the intensity calibration is 20%. The system temperatures were calibrated by injecting periodic noise and the accuracy of the intensity calibration is 20%. The system temperatures were calibrated by injecting periodic noise and the accuracy of the intensity calibration is 20%.

3. OBSERVATIONAL RESULTS

We detected five transitions of HC$_3$N, four transitions of HC$_7$N, and three transitions of HC$_9$N in the C and Ku band. The hyperfine structure of HC$_3$N $J = 6–5$, $F = 5–4$ at 15974.9336 MHz was resolved for the first time. Ohishi & Kaifu (1998) detected HC$_3$N $J = 6–5$ in TMC-1 with the Nobeyama 45 m radio telescope. The spectral resolution was 37 KHz ($\sim 0.7$ km s$^{-1}$) at 15 GHz) in their observation. The separation between HC$_3$N $J = 6–5$, $F = 4–4$ and HC$_3$N $J = 6–5$ was 32 KHz, thus the hyperfine structure was not resolved at the time. Two hyperfine components of HC$_3$N ($J = 13–12$, $F = 12–11$ at 7553.463 MHz and HC$_3$N $J = 13–12$, $F = 14–13$ at 7553.474) were detected. The spectral line profiles of HC$_3$N $J = 6–5$, HC$_7$N $J = 15–14$, and HC$_9$N $J = 31–30$ are also shown in Figure 1.

C$_3$S 3–2 was detected with a peak intensity of 0.46 K. The spectral line profile of C$_3$S $J = 3–2$ is shown in Figure 2 (upper panel).

The four fine and hyperfine structure components of the $J = 13–2/11–2$ transition of C$_2$H were detected with a peak intensity of 52–76 mK. The doublet lines with partially resolved hyperfine structures of $J = 31/2–29/2$ lines of C$_2$H were also detected. The intensity ratio of C$_2$H to C$_3$H is about 6:1. The spectral line profiles of the $J = 13/2–11/2$ transitions of C$_2$H $^2H_2[^3]J_{3/2}$ and the $J = 31/2–29/2$ transitions of C$_2$H $^2H_2[^1]J_{3/2}$ are shown in Figure 2 (lower panel).

The $^{13}$C substitutions of HC$_3$N (H$^{13}$CCCN, HC$^{13}$CCN, and HCC$^{13}$CN) $J = 2–1$ were also detected. The spectral line profiles of HC$_3$N and its $^{13}$C isotopomers are shown in Figure 3. The intensity of HCC$^{13}$CN is stronger than HC$^{13}$CCN and H$^{13}$CCCN, with the difference in the peak intensities at a level of about 4$\sigma$ ($\sigma \sim 4$ mK). On the other hand, there is no significant difference in intensity between the HC$^{13}$CCN and H$^{13}$CCCN lines. This is similar to observations of TMC-1 (Takano et al. 1998). This result indicates that the abundance difference between H$^{13}$CCCN and HC$^{13}$CCN, and HCC$^{13}$CN is not specific to TMC-1, but seems to be common to carbon-chain-rich clouds. H$^{13}$CCCN $J = 2–1$, HC$^{13}$CCN $J = 2–1$, and HCC$^{13}$CN $J = 2–1$ have been observed in TMC-1 with the Nobeyama 45 m telescope (Ohishi & Kaifu 1998; Takano et al. 1998; Kaifu et al. 2004). Limited by their spectral resolution
Figure 1. Upper left: *Herschel* SPIRE 500 μm dust continuum emission (gray-scale; André et al. 2010) toward HC₅N clump Serpens South 1a. Overlaid are NH₃ (1, 1) integrated intensity contours (dark and light gray contours) and HC₅N 21–20 integrated intensity contours (red, at intervals of 0.15 K km s⁻¹). The 32″ FWHM GBT beam at 23 GHz is shown by the hashed circle. White crosses show class 0 and class I protostar locations (Friesen et al. 2013). The 54″ FWHM TMRT beam at 18 GHz (yellow circle) and 121″ FWHM TMRT beam at 8 GHz (blue circle) are shown. Upper right: spectral line profiles of HC₅N in Serpens South 1a. The systemic velocity is 7.6 km s⁻¹. Lower left: spectral line profiles of HC₇N. Lower right: spectral line profiles of HC₉N. The positions of the hyperfine components of HC₇N and HC₉N are indicated with arrows.
(37 kHz, ~0.6 km s\(^{-1}\) at 18 GHz), the hyperfine components of these transitions were partially resolved. Resolved hyperfine components including the weak satellite components are detected for the first time here.

The line parameters are summarized in Table 2, including peak temperature (\(T_{\text{MB}}\)), FWHM linewidth, centroid velocity, integrated line intensity (\(\int T_{\text{MB}}\) dv), and column density. These parameters and their errors are derived by fitting the Gaussian profile to each spectrum. Because the signal-to-noise ratio is not high enough, it is difficult to fit the weaker hyperfine component (\(^2\Pi_{3/2} 31/2-29/2\) e) of C\(_2\)H well. We can see from Table 2 that the centroid velocities and FWHM linewidths of these carbon-chain molecule lines are similar, around 7.6 km s\(^{-1}\) and 0.6 km s\(^{-1}\), respectively, suggesting that these emissions come from similar regions. The linewidths are consistent with GBT observations of HC\(_2\)N in this source (0.56 km s\(^{-1}\); Friesen et al. 2013). The linewidths are significantly higher than those in TMC-1 and Lupus-1A,
which are reported to be 0.2–0.3 km s\(^{-1}\) (Li & Goldsmith 2012; Sakai et al. 2010b), implying that these emissions come from more complex and active regions than the other two sources.

4. DISCUSSION

4.1. Column Densities of Carbon-chain Molecules

As shown in Figure 1, the size of the HC\(_3\)N clump in Serpens South 1a is larger than the FWHM TMRT beam in the Ku band, but smaller than the FWHM TMRT beam in the C band. Thus it is inappropriate to estimate the rotational temperature and column density with rotational diagrams. Transitions in the 16–18 GHz range were used to derive the column densities of each molecule, and the lines that were used to derive column densities are labeled with “a” in Table 2. According to Figure 1, the size of the HC\(_3\)N clump in Serpens South 1a is about 2 arcmin, therefore, the beam filling factor is \(\sim 1\). By assuming local thermodynamic equilibrium (LTE) conditions and optical thinness for all the molecules, the column densities of these species are estimated with the following equation (Cummins et al. 1986):

\[
N = \frac{3kW}{8\pi\nu S\mu^2} \frac{T_{ex}}{T_{ex} - T_{bg}} \times Q(T_{ex}) \exp\left(\frac{E_u}{kT_{ex}}\right) (1)
\]

where \(k\) is the Boltzmann constant in erg K\(^{-1}\), \(W\) is the observed line integrated intensity in K km s\(^{-1}\), \(\nu\) is the frequency of the transition in Hz, and \(S\mu^2\) is the product of the total torsion–rotational line strength and the square of the electric dipole moment. \(T_{ex}\) and \(T_{bg}\) are the excitation temperature and background brightness temperature, respectively. \(E_u/k\) is the upper level energy in K, and \(Q(T_{ex})\) is the partition function. The values of \(E_u/k\) and \(S\mu^2\) were taken from the “SPLATLOGUE” spectral line catalogs. Friessen et al. (2013) derived a kinetic temperature of 10.8 K from observation of NH\(_3\). Usually, the kinetic temperature is larger than the excitation temperature in starless cores. We adopt an excitation temperature of 7 K, which is similar to those in TMC-1 (Bell et al. 1998; Sakai et al. 2007a) and Lupus-1A (Sakai et al. 2010b). The partition function \(Q(T_{ex})\) of each molecule is estimated by fitting the partition function at different temperatures given in CDMS. For most of our molecules, increasing the excitation temperature by 2 K would increase or decrease the resulting column density by less than 10%. The maximum variation comes from HC\(_9\)N, in which an increase in excitation temperature of 2 K would decrease the column density by 30%. The derived column densities and their errors are listed in Table 2. The errors come from the uncertainties of integrated intensities, which are obtained by Gaussian fitting. Decreasing the excitation temperature by 2 K would increase or decrease the resulting column density by less than 10% for most of our molecules. The maximum variations come from HC\(_7\)N and HC\(_9\)N, in which a decrease in excitation temperature of 2 K would increase the column density by 32% and 110%, respectively.

The column densities of these carbon-chain molecules range from \(10^{12}\) to \(10^{13}\) cm\(^{-2}\). Figure 4 shows a comparison of the column densities between Serpens South 1a, TMC-1, and Lupus-1A. We can see from Figure 4 that the column densities of long carbon-chain molecules in Serpens South 1a are comparable to those in TMC-1 and Lupus-1A. Thus we can say that the long carbon-chain molecules in Serpens South 1a are as abundant as in TMC-1. Therefore, like Lupus-1A, Serpens South 1a could also be regarded as a “TMC-1 like source.” This provides further evidence that the extraordinary richness of carbon-chain molecules in TMC-1 should not be ascribed to some special regional reasons, but should be considered as a more general phenomenon.

The abundance ratio for HC\(_7\)N:HC\(_9\)N is (2.0 \(\pm\) 0.2):1, which is similar to the abundance ratios found for TMC-1 and Lupus-1A, 4.8 and 2.5, respectively (Sakai et al. 2008, 2010b). The abundance ratio for C\(_6\)H:HC\(_7\)N is calculated to be (1.8 \(\pm\) 0.1):1, which seems to be less steep than the ratios observed in TMC-1 and Lupus-1A, 6.5 and 10, respectively (Br"unken et al. 2007; Sakai et al. 2008, 2010b). However, it should be noted that the column density is derived from one rotational transition of each molecule in this paper. In this case, the column densities of C\(_6\)H and C\(_8\)H or (HC\(_7\)N and HC\(_9\)N) are derived from transitions with different upper-state energies (see Table 1). So variation of the rotation temperature will affect the column densities for the two molecules differently. In general, the rotation temperature tends to be higher for longer chains (e.g., Bell et al. 1998; Ohishi & Kaifu 1998). As calculated above, if the rotation temperature of HC\(_9\)N is higher than HC\(_7\)N by 2 K,
the abundance ratio for HC$_7$N:HC$_9$N could be higher by $\sim$30%. If the rotation temperature of C$_8$H is higher than C$_6$H by 2 K, the abundance ratio could be higher by about 3%. Our results suggest that the abundance ratio for HC$_7$N:HC$_9$N is similar to those in TMC-1 and Lupus-1A, while the abundance ratio for C$_6$H:C$_8$H is statistically significantly lower than those in TMC-1 and Lupus-1A.

4.2. Abundance Ratio of HC$_3$N Isotopomers

The study of $^{13}$C isotopic fractionation provides a way to discriminate the formation mechanism of carbon-chain molecules (Takano et al. 1998). Numerical calculations suggest that molecules formed from carbon atoms have carbon isotope ratios (CX$/^{13}$CX) greater than the elemental abundance ratio of $[^{12}$C/$^{13}$C], while molecules formed from CO molecules have CX$/^{13}$CX ratios smaller than $[^{12}$C/$^{13}$C] (Furuya et al. 2011). We investigate the $^{13}$C isotopic fractionation with observations of $^{13}$C isotopologues of HC$_3$N in Serpens South 1a.

The HC$_3$N 2–1 transition has six hyperfine components, all of which were clearly seen in our spectra. We calculated the optical depth of HC$_3$N using the “hfs” fitting method (McGee et al. 1977) in the GILDAS CLASS package and found that it is optically thin, with an optical depth smaller than 0.1, see Figure 3. This is obviously smaller than in TMC-1, in which an optical depth of 0.47 was obtained from the HC$_3$N $J = 2$–1 transition (Li & Goldsmith 2012), suggesting that the column density of HC$_3$N in Serpens South 1a should be lower than that in TMC-1 at the same temperature. The column densities of the normal and the $^{13}$C isotopomers of HC$_3$N were calculated assuming LTE using Equation (1), also with the excitation temperature of 7 K. The integrated intensity (W) and $S$/$\sigma^2$ of the strongest hyperfine components were used to derive the column densities for the $^{13}$C isotopomers of HC$_3$N. We did not use the strongest component to derive the column density of the normal HC$_3$N because of its larger uncertainty in comparison with other components. Lines that were used for analysis were labeled with “a” in Table 2. The column densities obtained are listed in Table 2. The column density of normal HC$_3$N was comparable to that of TMC-1 ((1.6 $\pm$ 0.1) $\times$ 10$^{14}$ cm$^{-2}$; Takano et al. 1998). The ratios of the column densities of the three $^{13}$C isotopic species are 1.00:1.11 $\pm$ 0.15:1.47 $\pm$ 0.18 for [H$^{13}$CCCN]:[HC$^{13}$CCN]:[HCC$^{13}$CN]. The results presented here are similar to TMC-1, in which the abundance ratios are observed to be 1.0:1.0:1.4 for [H$^{13}$CCCN]:[HC$^{13}$CCN]:[HCC$^{13}$CN] at the cyanopolyne peak of TMC-1. This result implies that the $^{13}$C isotope is also concentrated in the carbon atom adjacent to the nitrogen atom in HC$_3$N, which supports the idea that C$_2$H$_2$+CN is probably the most important reaction in producing HC$_3$N (cf. Takano et al. 1998).

The carbon isotopic ratios ($^{12}$C/$^{13}$C) were further calculated from the obtained column densities of the normal and isotopic species of HC$_3$N. The carbon isotopic ratios obtained from H$^{13}$CCCN, HC$^{13}$CCN, and HCC$^{13}$CN are 78 $\pm$ 9, 70 $\pm$ 8, and 53 $\pm$ 4. The average $^{12}$C/$^{13}$C ($\sim$ 70) does not significantly deviate from the value of 70 in the solar neighborhood (Wilson & Rood 1994).

The [HC$_3$N]/[H$^{13}$CCCN], [HC$_3$N]/[HC$^{13}$CCN], and [HC$_3$N]/[HCC$^{13}$CN] ratios were derived to be 79 $\pm$ 11, 75 $\pm$ 10, and 45 $\sim$ 55 in TMC-1 (Takano et al. 1998). Therefore, the [HC$_3$N]/[H$^{13}$CCCN] and [HC$_3$N]/[HC$^{13}$CCN] ratios are similar for TMC-1 and Serpens South 1a. Langer & Graedel (1989) modeled the time evolution of the $^{12}$C/$^{13}$C ratios of various species with an ion–molecule chemistry of nitrogen-, oxygen-, and carbon-bearing molecules and isotopic ratios. They found that the ratios depend sensitively on physical conditions like temperature and density, implying similar physical evolutionary stages for Serpens South 1a and TMC-1. Observations toward more sources are needed to
obtain a full understanding of the behavior of $^{13}$C species in molecular clouds.

5. SUMMARY

We carried out carbon-chain molecular line observations toward Serpens South 1a with the TMRT. Several carbon-chain molecules were detected, including HC$_3$N, HC$_5$N, HC$_6$N, C$_2$S, C$_6$H, C$_8$H, and $^{13}$C substitutions of HC$_3$N. For the first time, some transitions and hyperfine components from HC$_3$N, HC$_5$N, and $^{13}$C substitutions of HC$_3$N were detected or resolved.

We calculated the column densities of these molecules and found that the column densities of these carbon-chain molecules in Serpens South 1a are comparable to those in two other carbon-chain molecule rich sources, TMC-1 and Lupus-1A. Thus this source could be regarded as another “TMC-1 like source.” The column density ratio of HC$_7$N:
HC$_3$N is similar to those in TMC-1 and Lupus-1A, while the abundance ratio of C$_2$H:C$_3$H seems to be statistically significantly lower than those in TMC-1 and Lupus-1A.

We also derived the abundance ratios of HC$_3$N isomers, and made a comparison with TMC-1. We found an average $^{12}$C/$^{13}$C ratio of about 67 ± 7, which does not significantly deviate from the value in the solar neighborhood. There is no difference in the carbon isotopic ratios between TMC-1 and Serpens South 1a, reflecting similar physical evolutionary conditions for these two sources.

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Figure 4. Comparison of the column densities between Serpens South 1a, TMC-1, and Lupus-1A. The 1σ errors of column densities are also shown. The column densities of Serpens South 1a are comparable to those of TMC-1 and Lupus-1A, thus Serpens South 1a could be regarded as another “TMC-1 like source.” The column densities of HC$_3$N, HC$_5$N, and HC$_{11}$N in TMC-1 are taken from Takano et al. (1998), Takano et al. (1990), and Bell et al. (1997), respectively. The column densities of C$_3$H and C$_4$H in TMC-1 are taken from Sakai et al. (2007b) and Br{"u}nken et al. (2007), respectively. The column densities of C$_3$S in TMC-1 are taken from Yamamoto et al. (1987). The column densities of the carbon-chain molecules in Lupus-1A are taken from Sakai et al. (2010b).