ALMA detection of ethyl cyanide and methyl formate in the hot molecular core IRAS 18566+0408

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ABSTRACT

In millimeter/submillimeter wavelength, the studies of the complex molecular emission lines towards the hot molecular cores demonstrate valuable details about the chemical composition and massive star formation processes. We present the interferometric detection of rotational molecular emission lines of complex organic species ethyl cyanide (C$_2$H$_5$CN) and methyl formate (CH$_3$OCHO) towards the hot molecular core IRAS 18566+0408 using data of Atacama Large Millimeter/Submillimeter Array (ALMA). We detected a total of three unblended strong rotational emission lines of ethyl cyanide and eight strong rotational emission lines of methyl formate between the frequency range of 85.64–100.42 GHz with ALMA band 3 observation. We applied the rotational diagram method under the Local Thermodynamic Equilibrium (LTE) conditions to determine the molecular column density ($N$) in cm$^{-2}$ and rotational temperature ($T_{rot}$) in K. The estimated statistical column density of ethyl cyanide was $N$(C$_2$H$_5$CN) = $(3.50 \pm 0.68) \times 10^{15}$ cm$^{-2}$ with rotational temperature $T_{rot} = 150 \pm 2.5$ K and methyl formate was $N$(CH$_3$OCHO) = $(1.55 \pm 0.31) \times 10^{16}$ cm$^{-2}$ with rotational temperature $T_{rot} = 150 \pm 2.8$ K. Additionally, we also fitted the LTE model spectrum over the original transitions of detected C$_2$H$_5$CN and CH$_3$OCHO spectral lines using the Markov Chain Monte Carlo (MCMC) algorithm to extract the line parameters and to verify the obtained column density using rotational diagram method. We estimated the fractional abundance of ethyl cyanide and
methyl formate towards the hot molecular core IRAS 18566+0408 relative to H$_2$ as $1.66 \times 10^{-9}$ and $7.38 \times 10^{-9}$ respectively where $N$(H$_2$) = $2.1 \times 10^{24}$ cm$^{-2}$. Except C$_2$H$_5$CN and CH$_3$OCHO, we also detected the emission lines of simple organic molecules SO, CH$_3$CO, HC$_3$N, H$_2$CS, HC$^{13}$CCN, HCC$^{13}$CN, and CH$_3$CHO towards IRAS 18566+0408.

Subject headings: ISM: individual objects (IRAS 18566+0408) – ISM: jets and outflows – ISM: kinematics and dynamics – stars: formation – stars: massive

1. Introduction

In the interstellar medium, the hot molecular cores exhibit the rich chemical complexity and nursery of simple and complex molecular gases (Herbst & van Dishoeck 2009). The hot molecular core regions are chemically rich which has a big influence on how the interstellar medium evolves (Tan et al. 2014; van Dishoeck & Black et al. 1998). Several complex organic molecules were detected towards the many hot molecular cores in past (Herbst & van Dishoeck 2009). The complex saturated organic molecules like CH$_3$OCHO, CH$_3$OCH$_3$, CH$_3$CH$_2$OH, CH$_2$CHCN, and C$_2$H$_5$CN have detected in many major hot molecular core regions like Orion-KL, Sagittarius B2, and W51 after several years of observations (Cummins et al. 1986; Turner 1989; Turner & Steimle 1985). These saturated molecules were first studied towards the hot molecular cores using a large beam single-dish radio telescope where the location and emission lines were not well constrained. The emission lines of complex molecular species usually arise at $\leq$ 0.2 pc diameter compact hot molecular core regions as found by different interferometric arrays. The emission lines of complex organic molecules mainly arise from the core of the hot molecular cloud and these molecular cores also contain high-velocity H$_2$O masers. These physical properties were also observed in some common hot molecular cores like Orion-KL, Sgr B2, G34.3+0.2, and W51 (Wright et al. 1996; Miao et al. 1995; Mehringer & Snyder 1996; Zhang et al. 1998). A huge amount of dust particles were observed around the hot molecular cores which were observed only in millimeter-wavelength interferometric observations. In the hot molecular core, grain-surface chemistry plays an important role in the formation of the complex organic molecules (Caselli et al. 1993).

The hot molecular core candidate IRAS 18566+0408 was located at a 6.7 kpc distance (Araya et al. 2004; Molinari et al. 1996). The maser water (H$_2$O) and methanol (CH$_3$OH) at frequency 22 GHz and 6.7 GHz were strongly evident in the hot molecular core IRAS 18566+0408 (Beuther et al. 2002). The weak radio continuum emission in centimeter wavelength was also detected from the dust around the IRAS 18566+0408 (Araya et al. 2005). The hot molecular core region IRAS 18566+0408 was classified as a massive disk candidate.
The maser H$_2$CO at 6 cm wavelength was found from the IRAS 158566+0408 (Araya et al. 2005). Earlier, the maser H$_2$CO at wavelength 6 cm were also found toward five regions in the Milky way, molecular clouds, and toward Orion BN/KL (Araya et al. 2002; Araya et al. 2006). The radio continuum emission of IRAS 18566+0408 was resolved with the VLA in the 1.3 and 6 cm wavelengths and showed four components which were consistent with an ionized jet (Hofner et al. 2017). The emission lines of NH$_3$ with transition J = 1,1 and J = 2,2 were detected by the single-dish radio telescope towards IRAS 18566+0408 (Miralles et al. 1994; Molinari et al. 1996; Sridharan et al. 2002) and later VLA imaged these species using interferometric technique (Zhang et al. 2007). Recently, CH$_3$CN, CH$_3$OH, OCS, $^{12}$CO, $^{13}$CO, and SO were detected towards IRAS 18566+0408 using Submillimeter Array (SMA) (Silva et al. 2017).

The interstellar complex organic nitrile molecule ethyl cyanide (C$_2$H$_5$CN) was also known as propanenitrile or propionitrile. Earlier, this complex species has been observed mainly in hot molecular clouds in the frequency range 40–950 GHz (Johnson et al. 1977; Schilke et al. 2001; White et al. 2003). The Berkeley-Illinois-Maryland Association (BIMA) array detected the partially blended emission lines of C$_2$H$_5$CN in Sgr B2 (N-LMH) with estimated column density $6 \times 10^{16}$ cm$^{-2}$ (Miao et al. 1995; Mehringer & Snyder 1996). Earlier, Miao & Snyder (1997) created first full synthesis imaging of C$_2$H$_5$CN from Sgr B2 using BIMA Array and NRAO 12 m telescope and they estimated the column density of C$_2$H$_5$CN was $\sim 9.6 \times 10^{17}$ cm$^{-2}$. The column densities of C$_2$H$_5$CN in Orion-KL and G34.3+0.2 were 3$\times 10^{16}$ and 3$\times 10^{15}$ cm$^{-2}$ respectively (Wright et al. 1996; Mehringer & Snyder 1996). Earlier, three $^{13}$C isotopologues of ethyl cyanide, $^{13}$CH$_2$CH$_2$CN, CH$_3^{13}$CH$_2$CN, and CH$_3$CH$_2^{13}$CN were observed from the Orion hot molecular cloud in the frequency range 80–40 GHz and 160–360 GHz (Demyk et al. 2007). Recently, the emission lines of C$_2$H$_5$CN were detected in the atmosphere of Saturn largest moon Titan between the frequency 222–241 GHz using ALMA with vertical column density $(1–5) \times 10^{15}$ cm$^{-2}$ (Cordiner et al. 2014). We reported the first detection of the C$_2$H$_5$CN towards the hot molecular core region IRAS 18566+0408 using ALMA.

Alongside ethyl cyanide (C$_2$H$_5$CN), the complex organic molecule methyl formate (CH$_3$OCHO) was one of the most abundant organic molecular species which was specially found in both high mass and low mass star formation regions (Cazaux et al. 2003; Brown et al. 1975). In the interstellar medium, methyl formate (CH$_3$OCHO) was one of the complex organic molecule which was known as an example of ester. In the hot molecular clouds, methyl formate (CH$_3$OCH$_3$) was one of the known molecule which was also responsible for the formation of multiple rotational transitions of other ester types compounds. Methyl formate was first detected towards the Sgr B2(N) (Brown et al. 1975). Earlier, many chemical formation models in the interstellar medium indicated the complex molecule methyl formate
Table 1: LTE fitted line parameters of the observed molecular lines towards IRAS 18566+0408

| Species         | Frequency [GHz] | Transition                  | $E_u^*$ [K] | $A_{ij}$ [s$^{-1}$] | $N$ [cm$^{-2}$] | $T_{ex}$ [K] | Optical depth [τ] | FWHM [km s$^{-1}$] | V LSR [km s$^{-1}$] | Remark          |
|-----------------|-----------------|-----------------------------|-------------|---------------------|----------------|-------------|------------------|------------------|------------------|-----------------|
| C$_2$H$_5$CN    | 98.6102         | 11(3,3)–10(3,3)             | 38.89       | 7.32×10$^{-5}$     | (3.50±0.48)×10$^{15}$ | 150±2.1      | 2.58×10$^{-4}$  | 4.50±0.18        | 83.50            | Non blend       |
| C$_2$H$_5$CN    | 98.7011         | 11(3,8)–10(3,7)             | 38.40       | 7.35×10$^{-5}$     | (3.50±0.52)×10$^{15}$ | 150±2.7      | 2.07×10$^{-4}$  | 4.50±0.15        | 83.50            | Non blend       |
| C$_2$H$_5$CN    | 99.0815         | 11(2,9)–10(2,8)             | 33.00       | 7.90×10$^{-5}$     | (3.50±0.58)×10$^{15}$ | 150±1.1      | 2.26×10$^{-4}$  | 4.50±0.09        | 83.50            | Non blend       |
| CH$_3$CO       | 98.6868         | J = 8(3,5)–7(3,4), F = 0–0 | 27.24       | 1.20×10$^{-5}$     | 1.55×10$^{-10}$      | 150±1.3      | 6.67×10$^{-3}$  | 4.50±0.27        | 85.00            | Non blend       |
| CH$_3$CO       | 98.7026         | J = 8(4,5)–7(4,4), F = 1–1 | 31.90       | 1.02×10$^{-5}$     | 1.55×10$^{-10}$      | 150±2.5      | 5.60×10$^{-3}$  | 4.50±0.35        | 85.00            | Non blend       |
| CH$_3$CO       | 98.7120         | J = 8(4,5)–7(4,4), F = 1–1 | 31.90       | 1.02×10$^{-5}$     | 1.55×10$^{-10}$      | 150±2.5      | 5.40×10$^{-3}$  | 4.50±0.21        | 85.00            | Non blend       |
| CH$_3$CO       | 98.7479         | J = 8(4,4)–7(4,3), F = 2–2 | 31.90       | 1.02×10$^{-5}$     | 1.55×10$^{-10}$      | 150±2.1      | 5.48×10$^{-3}$  | 4.50±0.29        | 85.00            | Non blend       |
| CH$_3$CO       | 98.7923         | J = 8(4,4)–7(4,3), F = 2–2 | 31.90       | 1.02×10$^{-5}$     | 1.55×10$^{-10}$      | 150±1.8      | 5.66×10$^{-3}$  | 4.50±0.32        | 85.00            | Non blend       |
| CH$_3$CO       | 100.2946        | J = 8(3,5)–7(3,4), F = 0–0 | 27.41       | 1.26×10$^{-5}$     | 1.55×10$^{-10}$      | 150±1.6      | 6.78×10$^{-3}$  | 4.50±0.34        | 85.00            | Non blend       |
| CH$_3$CO       | 100.3092        | J = 8(3,5)–7(3,4), F = 0–0 | 27.40       | 1.26×10$^{-5}$     | 1.55×10$^{-10}$      | 150±1.9      | 6.79×10$^{-3}$  | 4.50±0.29        | 85.00            | Non blend       |
| CH$_3$O        | 100.0945        | 3(1,5)–4(1,4)               | 27.48       | 1.26×10$^{-5}$     | 1.55×10$^{-10}$      | 150±1.7      | 1.50×10$^{-4}$  | 4.50±0.18        | 84.00            | Non blend       |
| HC$_3$N        | 100.0763        | 11–10                       | 26.32       | 7.74×10$^{-6}$     | (2.10±0.6)×10$^{15}$ | 150±2.6      | 4.19×10$^{-4}$  | 4.50±0.28        | 84.00            | Non blend       |
| SO             | 99.2998         | 2(1,1)–1(0,0)               | 9.23        | 1.15×10$^{-5}$     | (1.80±0.75)×10$^{15}$ | 100±1.3      | 3.77×10$^{-4}$  | 4.50±0.12        | 84.00            | Non blend       |
| SO             | 100.0296        | 3(4)–4(3)                   | 38.58       | 1.10×10$^{-6}$     | (1.80±0.72)×10$^{15}$ | 150±1.6      | 3.43×10$^{-4}$  | 4.50±0.39        | 84.00            | Non blend       |
| H$_2$CCN       | 99.7740         | 3(1,5)–2(2,2)               | 22.76       | 1.20×10$^{-5}$     | (5.20±0.28)×10$^{14}$ | 150±2.0      | 4.89×10$^{-4}$  | 4.50±0.12        | 85.00            | Non blend       |
| HCC$^+$CCN     | 99.6618         | 1(10)–10(9)                 | 28.70       | 7.57×10$^{-6}$     | (1.10±0.39)×10$^{15}$ | 150±2.1      | 6.59×10$^{-4}$  | 4.50±0.26        | 84.00            | Non blend       |
| HCC$^+$CCN     | 99.6614         | 1(10)–10(9)                 | 28.70       | 7.57×10$^{-6}$     | (1.10±0.45)×10$^{15}$ | 150±1.9      | 6.59×10$^{-4}$  | 4.50±0.29        | 84.00            | Non blend       |
| CH$_3$CHO      | 98.8631         | J = 5(4,4)–4(3,3), F = 2–2 | 16.59       | 2.99×10$^{-5}$     | (2.40±0.95)×10$^{15}$ | 150±2.7      | 3.11×10$^{-4}$  | 4.50±0.16        | 84.00            | Non blend       |
| CH$_3$CHO      | 98.9009         | J = 5(4,4)–4(3,3), F = 0–0 | 16.51       | 2.99×10$^{-5}$     | (2.40±0.89)×10$^{15}$ | 150±2.6      | 6.62×10$^{-3}$  | 4.50±0.46        | 84.00            | Non blend       |

$^a$E$_u$ denoted the upper energy of the detected molecular emission lines.
$^b$A$_{ij}$ denoted the Einstein coefficient of detected molecular emission lines.
$^c$N denoted column density of the detected molecular emission lines.
$^d$It is denoted excitation temperature which is define as $T_{ex} = \frac{h\nu}{ln(g_u / g_l)}\frac{n_u}{n_l}$ where $g_l$ and $g_u$ represented the statistical weights but $n_l$ and $n_u$ represented the number of particles in upper and lower state.

**Fig. 1.**.— ALMA detection of unblended rotational emission lines of C$_2$H$_5$CN between the frequency range of 85.64–100.42 GHz with their different transitions towards the hot molecular core IRAS 18566+0408. The properties of detected emission lines of C$_2$H$_5$CN and their spectral fitting parameters were shown in Tab. 1. The continuum emission has been completely subtracted from the emission spectrum. In the emission spectrum, the black colour line showed the observed transitions of C$_2$H$_5$CN, while the red colour line showed the synthetic spectra obtained from the best fitting of LTE model. The systematic velocity (V$_{LSR}$) of the line was ~83.50 km s$^{-1}$. The best fitted $\chi^2$ value for the emission lines of C$_2$H$_5$CN was ~0.92.
was formed after the evaporation of the methanol (CH$_3$OH) from grain mantle in the hot molecular cores (Millar et al. 1991). Garrod et al. (2008) presented the formation mechanism of methyl formate in gas-grain interaction but how to produce methyl formate in the interstellar medium using gas-phase reactions is not well understood. The methyl formate plays a major role in the formation of biopolymers. In G31.41+0.31 hot molecular cloud, the column density of CH$_3$OCHO was 3.4×10$^{18}$ cm$^{-2}$ (Isokoski, Bottinelli & van Dishoeck. 2013). Earlier, CH$_3$OCHO was also detected in the low mass protostar IRAS 16293–2422 (Cazaux et al. 2003). The emission lines of methyl formate were also observed in a solar-type star-forming region L 1157-B1, where the molecular outflow interacts with dense clouds (Arce et al. 2008). Later, Lefloch et al. (2017) claimed that the solar-type star-forming region L 1157-B1 was the factory of complex organic molecules. Earlier, Sakai et al. (2006) detected the emission lines of CH$_3$OCHO from NGC 1333 IRAS 4B, and these molecules can be used as a tracer in the hot molecular core regions. Therefore, CH$_3$OCHO was an important molecule in the grain surfaces of hot corinos and hot molecular cores. We detected CH$_3$OCHO first time in the hot molecular core candidate IRAS 18566+0808.

In this article, we presented the first interferometric detections of C$_2$H$_5$CN and CH$_3$OCHO between the frequency range of 85.64–100.4 GHz in the hot molecular core region IRAS 18566+0408 using ALMA band 3 observation. Additionally, we also detected the emission lines of simple organic molecules SO, CH$_2$CO, HC$_3$N, H$_2$^{34}CS, HC$^{13}$CCN, HCC$^{13}$CN, and CH$_3$CHO. In Sect. 2, we discussed the observations and data reductions. The result of the detection of ethyl cyanide, methyl formate, and other detected simple molecules was shown in Sect. 3. The discussion and conclusion were presented in Sect. 4 and 5.

2. Observations and data reduction

The interferometric millimeter-wavelength observation of hot molecular core or high mass star-forming region IRAS 18566+0408 was performed with Atacama Large Millimeter/Submillimeter Array (ALMA)\(^1\) using the band 3 (frequency range 84–116 GHz) observation. The observed phase center of IRAS 18566+0408 was $\alpha_{J2000}$: 18:59:10.000 and $\delta_{J2000}$: +04:12:16.000. During the observation, XX, YY, and XY-type signal correlators were used via the integration time 1360.800 s. The observation of the complex molecular spectral lines towards IRAS 18566+0408 was performed with band 3 having eight spectral bands covering the sky frequencies of 85.64–85.70 GHz, 86.29–86.35 GHz, 86.71–86.77 GHz, 86.80–86.86 GHz, 88.59–88.64 GHz, 89.14–89.20 GHz, 97.93–97.99 GHz, and 98.54–100.42 GHz. The

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1\(\text{https://almascience.nao.ac.jp/asax/}\)
Fig. 2.— ALMA detection of unblended rotational emission lines of CH$_3$OCHO between the frequency range of 85.64–100.42 GHz with their different transitions towards the hot molecular core IRAS 18566+0408. The properties of detected emission lines of CH$_3$OCHO and their spectral fitting parameters were shown in Tab. 1. The continuum emission has been completely subtracted from the emission spectrum. In the emission spectrum, the black colour line showed the observed transitions of CH$_3$OCHO, while the blue colour line showed the synthetic spectra obtained from the best fitting of the LTE model. The systematic velocity ($V_{LSR}$) of the line was $\sim 85.0$ km s$^{-1}$. The best fitted $\chi^2$ value for the emission lines of CH$_3$OCHO was $\sim 0.869$. 

ν = 98.6826 GHz
ν = 98.6112 GHz
ν = 98.6069 GHz
ν = 98.7120 GHz
ν = 98.7479 GHz
ν = 98.7923 GHz
ν = 100.2946 GHz
ν = 100.3082 GHz
Fig. 3.— ALMA detection of rotational emission lines of CH$_2$CO, HC$_3$N, SO, H$_2^{34}$C, HC$_{13}$CCN, HCC$_{13}$CN, and CH$_3$CHO between the frequency range of 85.64–100.42 GHz with their different transitions towards the hot molecular core IRAS 18566+0408. The properties of detected molecules and their spectral fitting parameters were shown in Tab. 1. The continuum emission has been completely subtracted. In the emission spectrum, the black colour line showed the observed transitions of detected molecules, while the red colour line showed the synthetic spectra obtained from the best fitting of LTE model.
Fig. 4.— Integrated emission map of C$_2$H$_5$CN in the hot molecular core region IRAS 18566+0408 at frequency 98.6102 GHz which was obtained after combining all the calibrated visibility data. The corresponding synthesized beam of the image was 2.383″×1.613″. The cyan color circles indicated the synthesized beam of the integrated emission map. The contour levels started at 0.5 mJy beam$^{-1}$ (3σ) increasing by a factor of $\sqrt{2}$. 
corresponding spectral resolution of the interferometric data was 122.07 kHz, 121.15 kHz, 122.01 kHz, 1128.91 kHz respectively. The observation was done on 24-March-2016. During the observation, a total of thirty-six antennas were used to study the complex molecular lines from IRAS 18566+0408. The solar planet Neptune was taken as flux calibrator, J1924–2914 was taken as bandpass calibrator, and J1830+0619 was taken as phase calibrator. The systematic velocity ($V_{LSR}$) of IRAS 18566+0408 was known to be $\sim$84.5 km s$^{-1}$ (Silva et al. 2017).

We used the Common Astronomy Software Application (CASA 5.4.1)$^2$ for initial data reduction and spectral imaging with the standard data reduction pipeline delivered by the ALMA observatory (McMullin et al. 2007). The continuum flux density of the flux calibrator Neptune for each baseline was scaled and matched with Butler-JPL-Horizons 2012 flux calibrator model with 5% accuracy using task SETJY (Butler 2012). Initially, we calibrated the bandpass and flux by flagging the bad data using CASA pipeline with task hifa_flagdata and hifa_bandpassflag. After the initial data reduction, we split the target data using task MSTRANSFORM with rest frequency in each spectral windows. We used the task UVCONTSUB for the continuum subtraction procedure from the UV plane in each raw data. After the continuum subtraction, we made the spectral image of IRAS 18566+0408 using task TCLEAN with the rest frequency of each spectral windows.

3. Results

3.1. Analysis of molecular emission lines towards the hot molecular core IRAS 18566+0408

For the identification of the molecular lines towards the hot molecular core candidate IRAS 18566+0408, we used CASSIS (developed by IRAP-UPS/CNRS) with Cologne Database for Molecular Spectroscopy (CDMS)$^3$ (Müller et al. 2005) and Jet Propulsion Laboratory (JPL)$^4$ (Pickett et al. 1998) spectroscopic molecular databases. We detected three strong unblended rotational emission lines of C$_2$H$_5$CN and eight strong rotational emission lines of CH$_3$OCHO between the frequency range of 85.64–100.42 GHz in the hot molecular core region IRAS 18566+0408. The observed emission spectra of C$_2$H$_5$CN and CH$_3$OCHO was extracted from ALMA spectral data cubes to make a 8.9" diameter circular region.

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$^2$https://casaguides.nrao.edu/

$^3$https://cdms.astro.uni-koeln.de/cgi-bin/cdmssearch

$^4$https://spec.jpl.nasa.gov/
Fig. 5.— Integrated emission map of CH$_3$OCHO in the hot molecular core region IRAS 18566+0408 at frequency 98.7120 GHz which was obtained after combining all the calibrated visibility data. The corresponding synthesized beam of the image was 2.391$''$×1.610$''$. The cyan color circles indicated the synthesized beam of the resultant integrated emission map. The contour levels started at 0.5 mJy beam$^{-1}$ (3σ) increasing by a factor of $\sqrt{2}$.

Fig. 6.— Rotational diagram of C$_2$H$_5$CN and CH$_3$OCHO. The black squares indicated the original statistical data points and the error bar indicated the red lines. The best-fitted column density and rotational temperature were shown on the upper right side of the image. The blue line indicated the best fitted single power-law over statistical data points.
centred at RA (J2000) = (18\,h\,59\,m\,09\,s.92), Dec (J2000) = (4°\,12′\,15″\,58). In Fig. 1 and 2, rotational molecular emission lines of C$_2$H$_5$CN and CH$_3$OCHO were shown. The spectral line parameters like upper energy ($E_u$), quantum numbers ($J'_{K_a}'_{K_c} - J''_{K_a''_{K'_c}}$), Full-Width Half Maximum (FWHM) and LSR velocity ($V_{LSR}$) of each transition were estimated after fitting a single Gaussian model over the observed transition of C$_2$H$_5$CN and CH$_3$OCHO were shown in Tab. 1. We also created the integrated emission map of C$_2$H$_5$CN and CH$_3$OCHO at frequency 98.6102 GHz and 98.7120 GHz which were shown in Fig. 4 and 5. The integrated emission maps clearly indicated that the emission lines of complex organic molecules C$_2$H$_5$CN and CH$_3$OCHO were mainly arose from the warm inner region of the IRAS 18566+0408.

Except for C$_2$H$_5$CN and CH$_3$OCHO, we also observed the evidence of some simple organic molecules in IRAS 18566+0408. We have observed molecular emission lines of simple organic molecules SO, CH$_2$CO, HC$_3$N, H$_2^{34}$CS, HC$^{13}$CCN, HCC$^{13}$CN, and CH$_3$CHO. The molecular spectrum of other detected molecules was shown in Fig. 3 and corresponding spectral properties were shown in Tab. 1. Between the observable frequency range, we detected the hyperfine transition lines only for CH$_3$CHO and SO but other molecules like CH$_2$CO, HC$_3$N, H$_2^{34}$CS, HC$^{13}$CCN, and HCC$^{13}$CN detected with single transition line. Earlier, Silva et al. (2017) detected the single transition emission line of SO with transition J = 6(5)–5(4) towards IRAS 18566+0408 using Submillimeter Array (SMA) and he postulated that SO is coming from an outflow of gases. We also detected the dual transition emission lines of SO with transitions J = 2(3)–1(2) and 5(4)–4(4) using ALMA but we have not detected any signature of the outflow of SO towards IRAS 18566+0408. The emission lines of CH$_2$CO, HC$_3$N, H$_2^{34}$CS, HC$^{13}$CCN, HCC$^{13}$CN, and CH$_3$CHO detected the first time towards IRAS 18566+0408.

3.2. Spatial distribution of ethyl cyanide and methyl formate towards IRAS 18566+0408

We calculated the source size or emitting diameter ($\theta_S$) of C$_2$H$_5$CN and CH$_3$OCHO by fitting the 2D Gaussian of the integrated emission map of C$_2$H$_5$CN and CH$_3$OCHO which was shown in Fig. 1 and 2. The source size is one of the important parameter during the fitting of the LTE model using CASSIS. The deconvolved beam size of the emitting region was calculated by the following equation

$$\theta_S = \sqrt{\theta_{50}^2 - \theta_{beam}^2}$$ (1)

where $\theta_{50} = 2\sqrt{\pi/ A}$ was the diameter of the circle whose area ($A$) was enclosing 50% line peak and $\theta_{beam}$ was the half-power width of the synthesized beam (Rivilla et al. 2017; Mondal
et al. 2021). We observed that the emission lines of C$_5$H$_5$CN and CH$_3$OCHO have a peak at the position of the continuum. The estimated emitting diameter or source size ($\theta_S$) of the complex molecule C$_2$H$_5$CN and CH$_3$OCHO was $\sim$1.20''. Our result clearly showed that the emitting diameters of the different detected transitions of C$_2$H$_5$CN and CH$_3$OCHO were less than the beam size of the emission map. This implied that the detected transitions of C$_2$H$_5$CN and CH$_3$OCHO were not well spatially resolved.

3.3. Calculation of column density ($N$) and rotational temperature ($T_{rot}$) using rotational diagram analysis

We used the rotational diagram method to obtain the column density ($N$) in cm$^{-2}$ and rotational temperature ($T_{rot}$) in K of detected emission lines of C$_2$H$_5$CN and CH$_3$OCHO in hot molecular core IRAS 18566+0408. We used the rotational diagram method because we assumed that the observed species were optically thin and they satisfied the Local Thermal Equilibrium (LTE) condition. The column density of optically thin lines can be written as (Goldsmith & Langer 1999),

$$N_{u}^{\text{thin}} = \frac{3g_u k_B \int T_{mb} dV}{8\pi^3 \nu S \mu^2}$$  \hspace{1cm} (2)

where, $k_B$ is the Boltzmann constant, $\int T_{mb} dV$ is the integrated intensity, $\mu$ is the electric dipole moment, $g_u$ is the degeneracy of the upper state, $\nu$ is the rest frequency, and the strength of the transition lines were indicated by $S$. Under the LTE conditions, the total column density of detected species can be written as,

$$\frac{N_{u}^{\text{thin}}}{g_u} = \frac{N_{\text{total}}}{Z(T_{rot})} \exp\left(-\frac{E_u}{k_B T_{rot}}\right)$$  \hspace{1cm} (3)

where $Z(T_{rot})$ is the partition function at extracted rotational temperature, $T_{rot}$ is the rotational temperature, and $E_u$ is the upper energy of the observed molecular lines. The Equation 3 can be rearranged as,

$$\ln\left(\frac{N_{u}^{\text{thin}}}{g_u}\right) = \ln(N) - \ln(Z) - \left(\frac{E_u}{k_B T_{rot}}\right)$$  \hspace{1cm} (4)

Equation 4 demonstrated the linear relationship between calculated column density and upper energy of the detected complex molecules. Using equation 4, we can estimate the rotational temperature and column density of the detected molecular species. During the rotational diagram analysis, we extracted the line parameters like FWHM, upper energy
$(E_u)$, line intensity, and integrated intensity ($\int T_{mb}dV$) using a single Gaussian fitting over the originally observed transition of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$. After the rotational diagram analysis, we found the column density of ethyl cyanide was $N(\text{C}_2\text{H}_5\text{CN}) = (3.50 \pm 0.68) \times 10^{15}$ cm$^{-2}$ with rotational temperature $T_{rot} = 150 \pm 2.5$ K. For methyl formate, the column density was $N(\text{CH}_3\text{OCHO}) = (1.55 \pm 0.31) \times 10^{16}$ cm$^{-2}$ with rotational temperature $T_{rot} = 150 \pm 2.8$ K. All detected transitions of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$ were shown in Tab. 1 and the computed rotational diagram was shown in Fig. 6. In the rotational diagram, the vertical red color error bars were the absolute uncertainty of $ln(N_u/g_u)$ and it was created from the error of the observed $\int T_{mb}dV$ which was measured using the fitting of single Gaussian model over observed transitions of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$.

### 3.4. Fitting of LTE model using Markov Chain Monte Carlo (MCMC) algorithm

After the identification of emission lines of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$ using the CDMS and JPL molecular databases, we used the Markov Chain Monte Carlo (MCMC) method in the CASSIS python interface for fitting the Local Thermodynamic Equilibrium (LTE) model over the original transitions of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$ to calculate the column density ($N$) in cm$^{-2}$, excitation temperature ($T_{ex}$) in K, optical depth ($\tau$) and FWHM in km s$^{-1}$ of the resultant emission spectrum. We applied the LTE method because we assumed that the observed transitions of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$ were optically thin and they are populated under all LTE conditions. After the fitting of the LTE model over the observed molecular emission spectrum, the best fit reduced $\chi^2$ value was calculated between the observed and simulated data, and the following equation was used to decrease the $\chi^2$ value

$$\chi^2_{red} = \frac{1}{\sum_{i=1}^{N_{spec}} N_i} \sum_{i=1}^{N_{spec}} N_i \sum_{j=1}^{N_i} \frac{(I_{obs,ij} - I_{model,ij})^2}{rms_i^2 + (cal_i \times I_{obs,ij})^2} \tag{5}$$

where, $I_{model,ij}$ and $I_{obs,ij}$ mean the intensity of the LTE model and original spectra in the channel $j$ of transition $i$ respectively. The calibration error is denoted by $cal_i$ and the rms of the spectrum $i$ is denoted by $rms_i$.

After the fitting of the LTE model over the original transition of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$, we estimated the resultant optical depth ($\tau$) of all emission lines were less than 1 that means the observed emission spectrum of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$ were optically thin. We have obtained column density ($N$) in cm$^{-2}$ and excitation temperatures ($T_{ex}$) in K of $\text{C}_2\text{H}_5\text{CN}$ and $\text{CH}_3\text{OCHO}$ by the MCMC calculations (Tab. 1) which were consistent with the column density ($N$) in cm$^{-2}$ and rotational temperatures ($T_{rot}$) in K of these molecules obtained by
the rotational diagram method which was described in the Section 3.3. After the spectral analysis using rotational diagram and LTE fitting using MCMC method, we found that the estimated column density and gas temperature are same for both of the methods. During fitting LTE model, we used the source size 1.20° (detail calculation presented in Sec. 3.2). The resultant physical parameters were shown in Tab. 1 and the resultant emission spectrum of C$_2$H$_5$CN and CH$_3$OCHO with best-fitting LTE syntetic spectra using MCMC algorithm was shown in Fig. 1 and 2. The fractional abundance of ethyl cyanide and methyl formate with respect to H$_2$ was f(C$_2$H$_5$CN) = 1.66×10$^{-9}$ and f(CH$_3$OCHO) = 7.38×10$^{-9}$ where the column density of hydrogen in IRAS 18566+0408 was N(H$_2$) = 2.1×10$^{24}$ cm$^{-2}$ (Hofner et al. 2017).

We also used the LTE model with MCMC method to estimate the physical properties of the other observed emission lines of SO, CH$_2$CO, HC$_3$N, H$_2$CS, HC$_{13}$CCN, HCC$_{13}$CN, and CH$_3$CHO in IRAS 18566+0408. The emission lines of SO and CH$_3$CHO were detected with multiple transitions, and the emission lines of CH$_2$CO, HC$_3$N, H$_2$CS, HC$_{13}$CCN, and HCC$_{13}$CN were detected with the single transition. The resultant physical parameters of the detected other molecular lines were shown in Tab. 1 and the LTE fitting emission spectrum was shown in Fig. 3.

4. Discussion

4.1. Comparison of ethyl cyanide (C$_2$H$_5$CN) and methyl formate (CH$_3$OCHO) column density with IRAS 18566+0408 and other hot molecular cores

Earlier, the complex molecule C$_2$H$_5$CN and CH$_3$OCHO were detected from several hot molecular clouds and we detected, for the first time, the emission lines of C$_2$H$_5$CN and CH$_3$OCHO in IRAS 18566+0408 with other molecular cores.

| Source           | Species             | Column density [cm$^{-2}$] | Remark                |
|------------------|---------------------|----------------------------|-----------------------|
| IRAS 18566+0408  | C$_2$H$_5$CN        | 3.50×10$^{15}$             | Our work              |
| G31.41+0.31      | C$_2$H$_5$CN        | 4.01×10$^{15}$             | Calcutt et al. 2014   |
| Sgr B2 (N)       | C$_2$H$_5$CN        | 1.20×10$^{18}$             | Belloche et al. 2009  |
| Orion KL         | C$_2$H$_5$CN        | 2.4×10$^{17}$              | Friedel & Looney 2008 |
| IRAS 18566+0408  | CH$_3$OCHO          | 1.55×10$^{16}$             | Our work              |
| G31.41+0.31      | CH$_3$OCHO          | 6.50×10$^{18}$             | Goria et al. 2021     |
| Sgr B2 (N)       | CH$_3$OCHO          | 1.20×10$^{18}$             | Belloche et al. 2016  |
| Orion KL         | CH$_3$OCHO          | 1.04×10$^{17}$             | Favre et al. 2011     |
CH$_3$OCHO towards IRAS 18566+0408. In the interstellar medium, the column density of ethyl cyanide (C$_2$H$_5$CN) towards the hot molecular cores were found in the order of $10^{15}$–$10^{18}$ cm$^{-2}$ (Mehringer & Snyder 1996; Miao & Snyder 1997) and our calculated column density of ethyl cyanide towards the hot molecular core IRAS 18566+0408 was also consistent within the range. Earlier, the first blended and torsional emission lines of C$_2$H$_5$CN was found from Sgr B2(N-LMH) (Mehringer et al. 2004). The emission line of C$_2$H$_5$CN was also detected from low mass protostar IRAS 16293-2422 with column density $9 \times 10^{14}$ cm$^{-2}$ (Cazaux et al. 2003). Cordiner et al. (2014) also detected the emission lines of C$_2$H$_5$CN in the atmosphere of Saturn largest moon Titan with vertical column density $(1–5) \times 10^{15}$ cm$^{-2}$. The observed column density of ethyl cyanide towards Titan was very similar to the column density of ethyl cyanide towards the hot molecular core IRAS 18566+0408.

After the calculation of the column density of C$_2$H$_5$CN and CH$_3$OCHO towards IRAS 18566+0408, we compared these values with other molecular cores G31.41+0.31, Sgr B2 (N), and Orion KL. The Fig. 7 showed a bar diagram which compared the column density of C$_2$H$_5$CN and CH$_3$OCHO between IRAS 18566+0408, G31.41+0.31, Sgr B2 (N), and Orion KL and corresponding values were shown in Tab. 2. The bar diagram indicated that the column density of C$_2$H$_5$CN in IRAS 18566+0408 was approximately similar with G31.41+0.31, $\sim$20 times lower than Orion KL, and $\sim$30 times lower than Sgr B2 (N). For the case of CH$_3$OCHO, column density in IRAS 18566+0408 was $\sim$10 times lower than Orion KL, and $\sim$20 times lower than G31.41+0.31 and Sgr B2 (N). The column density of C$_2$H$_5$CN and CH$_3$OCHO was small with respect to G31.41+0.31, Sgr B2 (N), and Orion KL which implied that the production rate of complex organic molecules in IRAS 18566+0408 was small with respect to G31.41+0.31, Sgr B2 (N), and Orion KL.

4.2. Possible formation mechanism of ethyl cyanide (C$_2$H$_5$CN) towards the hot molecular cores

In the surface chemical route, the complex nitrile molecule ethyl cyanide (C$_2$H$_5$CN) will produce via the reaction of C$_2$H$_5$ and CN towards hot molecular cores (C$_2$H$_5$ + CN $\rightarrow$ C$_2$H$_5$CN) (Belloche et al. 2009) but unfortunately the observation of C$_2$H$_5$ by radio techniques were very difficult because it is a nonpolar molecule. In the grain surface of the hot molecular core, the complex nitrile species C$_2$H$_5$CN will produce with the help of interstellar methyl cyanide (CH$_3$CN) and protonated CH$_3$. The possible chemical reaction is

\[ \text{CH}_3^+ + \text{CH}_3\text{CN} \rightarrow \text{C}_2\text{H}_5\text{CN}^+ + h\nu \]  
\[ \text{C}_2\text{H}_5\text{CN}^+ + e^- \rightarrow \text{C}_2\text{H}_5\text{CN} + \text{H} \]

The above chemical reaction was taken from UMIST 2012 astrochemistry reaction network
Fig. 7.— Bar diagram of the comparison of column density of C$_2$H$_5$CN and CH$_3$COCH$_3$ between the hot molecular cores IRAS 18566+0408, G31.41+0.31, Sgr B2 (N), and Orion KL. These column abundances were given in the Tab. 2 with their references.

Table 3: Destruction pathways of C$_2$H$_5$CN and CH$_3$OCHO with different types of chemical reactions towards the hot molecular cores.

| Reaction | Types                  | $\alpha$      | $\beta$ | $\gamma$ |
|----------|------------------------|---------------|---------|----------|
| C$_2$H$_5$CN+CRPHOT $\rightarrow$ CH$_3$CHCNH$^+$+H$^+$+e$^-$ | Cosmic ray-induced photoreaction | $1.30 \times 10^{-17}$ | 0.00 | 1122.50 |
| C$_2$H$_5$CN+CRPHOT $\rightarrow$ CN+C$_2$H$_5$ | Cosmic ray-induced photoreaction | $1.30 \times 10^{-17}$ | 0.00 | 2388.00 |
| CH$_4^+$+C$_2$H$_5$CN $\rightarrow$ C$_2$H$_5$CNH$^+$+CH$_3$ | Ion-neutral | $4.0 \times 10^{-9}$ | $-0.50$ | 0.00 |
| C$_2$H$_5$CN+OH $\rightarrow$ C$_2$H$_5$+HNCO | Neutral-neutral | $8.81 \times 10^{-14}$ | 6.00 | 500.00 |
| C$_2$H$_5$CN+OH $\rightarrow$ C$_2$H$_5$+HOCN | Neutral-neutral | $1.41 \times 10^{-14}$ | 3.37 | 0.00 |
| C$_2$H$_5$CN+ $h\nu$ $\rightarrow$ CH$_3$CHCNH$^+$+H$^+$+e$^-$ | Photoprocess | $6.20 \times 10^{-10}$ | 0.00 | 3.10 |
| C$_2$H$_5$CN+ $h\nu$ $\rightarrow$ CN+C$_2$H$_5$ | Photoprocess | $3.40 \times 10^{-9}$ | 0.00 | 2.00 |
| C$^+$+CH$_3$OCHO $\rightarrow$ COOCH$_4^+$+C | Charge exchange | $3.00 \times 10^{-9}$ | $-0.50$ | 0.00 |
| H$^+$+CH$_3$OCHO $\rightarrow$ COOCH$_4^+$+H | Charge exchange | $3.00 \times 10^{-9}$ | $-0.50$ | 0.00 |
| CH$_3$OCHO+CRPHOT $\rightarrow$ CO$_2$+CH$_4$ | Cosmic ray-induced photoreaction | $1.30 \times 10^{-17}$ | 0.00 | 1000.00 |
| CH$_3$OCHO+CRPHOT $\rightarrow$ COOCH$_4$+e$^-$ | Cosmic ray-induced photoreaction | $1.30 \times 10^{-17}$ | 0.00 | 500.00 |
| H$_3^+$+CH$_3$OCHO $\rightarrow$ H$_2$C$_2$O$_2^+$+H$_2$ | Ion-neutral | $3.00 \times 10^{-9}$ | $-0.50$ | 0.00 |
| H$_2$O$^+$+CH$_3$OCHO $\rightarrow$ H$_2$C$_2$O$_2^+$+H$_2$O | Ion-neutral | $3.00 \times 10^{-9}$ | $-0.50$ | 0.00 |
| HCO$^+$+CH$_3$OCHO $\rightarrow$ H$_2$C$_2$O$_2^+$+CO | Ion-neutral | $2.90 \times 10^{-9}$ | $-0.50$ | 0.00 |
| He$^+$+CH$_3$OCHO $\rightarrow$ HCOO$^+$+CH$_3$+He | Ion-neutral | $2.90 \times 10^{-9}$ | $-0.50$ | 0.00 |
| CH$_3$OCHO+ $h\nu$ $\rightarrow$ H$_2$CO+H$_2$CO | Photoprocess | $1.38 \times 10^{-9}$ | 0.00 | 1.70 |
(McElroy et al. 2013). In reaction 1, the methyl cyanide (CH$_3$CN) reacts with protonated methane (CH$_3^+$) to create C$_2$H$_5$CNH$^+$ via radiative association reaction and corresponding reaction coefficients are $\alpha = 9.0 \times 10^{-11}$, $\beta = -0.50$, and $\gamma = 0.00$ which was calculated using the Arrhenius equation. The complex molecule C$_2$H$_5$CN produces after the dissociative recombination of C$_2$H$_5$CNH$^+$ in the interstellar grains with reaction coefficients $\alpha = 6.32 \times 10^{-7}$, $\beta = -0.76$, and $\gamma = 0.00$ which shown in reaction 2. Recently, the emission lines of CH$_3$CN was detected from IRAS 18566+0408 using SMA with column density $7.3 \times 10^{16}$ cm$^{-2}$ (Silva et al. 2017). This possible formation mechanism of C$_2$H$_5$CN towards IRAS 18566+0408 indicated that the CH$_3$CN molecule acted as a precursor of C$_2$H$_5$CN. In the hot molecular cores, the C$_2$H$_5$CN molecule will destroy via cosmic ray-induced photoreaction, ion-neutral, neutral-neutral, and photoprocess chemical reactions which provided in Tab. 3 (McElroy et al. 2013).

### 4.3. Possible formation mechanism of methyl formate (CH$_3$OCHO) towards the hot molecular cores

In the interstellar medium, the methyl formate (CH$_3$OCHO) was first detected towards the hot molecular core region Sgr B2 (Brown et al. 1975). The emission lines of CH$_3$OCHO have been also detected in hot corinos and outflow regions (Bottinelli et al. 2007; Arce et al. 2008). In the hot molecular core IRAS 18566+0408, the complex organic molecule methyl formate (CH$_3$OCHO) can be created on the surface of dust grains by the reaction between CH$_3$O and HCO, and this mechanism was the same in the case of all hot molecular cores (Garrod et al. 2008; Gorai et al. 2021). The chemical simulation between CH$_3$O and HCO shows that these radicals are mobile around 30–40 K (Gorai et al. 2021). According to the simulation of Fig. 1 in Garrod (2013), it is clear that the gas phase methyl formate (CH$_3$OCHO) in the hot molecular core region mainly arose from the ice phase. The increase of UV photodissociation of methanol (CH$_3$OH) in the hot molecular cores leads to the formation of CH$_2$O, CH$_3$O, and CH$_3$ around 40 K temperature (Gorai et al. 2021). At temperature $T \sim 40$ K in gas phase, the H$_2$CO and protonated CH$_3$OH react and create H$_5$C$_2$O$_2^+$ (Gorai et al. 2021). The methyl formate (CH$_3$OCHO) would be created in the hot molecular core via the electron recombination of H$_5$C$_2$O$_2^+$ (H$_5$C$_2$O$_2^+$+e$^-$ $\rightarrow$CH$_3$OCHO+H) (Bonfand et al. 2019). Using the UMIST 2012 astrochemistry chemical network (McElroy et al. 2013), we found the reaction coefficients of the given reaction H$_5$C$_2$O$_2^+$+ e$^-$ $\rightarrow$CH$_3$OCHO+H was $\alpha = 1.50 \times 10^{-7}$, $\beta = -0.50$, and $\gamma = 0.00$. The destruction pathways of complex molecule CH$_3$OCHO via charge exchange, cosmic ray-induced photoreaction, ion-neutral, and photoprocess chemical reactions towards the hot molecular core regions was presented in Tab. 3 which was adopted from UMIST 2012 astrochemistry reaction network (McElroy et al. 2013).
Earlier, Balucani et al. (2015) proposed that the dimethyl ether (CH$_3$OCH$_3$) was the precursor of CH$_3$OCHO in a cold environment with gas-phase reaction. The single transition line of dimethyl ether (CH$_3$OCH$_3$) with transition J=17(2,15)–16(3,14) was detected towards IRAS 18566+0408 using SMA (Silva et al. 2017) but detection of a single transition line of complex molecule is not strong conclusive evidence of presence of the gas in the hot molecular core. The complex molecule CH$_3$OCHO can be produced through both gas-phase reaction and grain surface reaction (Gorai et al. 2021). Recently, Ishibashi et al. (2021) proposed a formation mechanism of CH$_3$OCHO in the hot molecular core region between the reaction of CH$_3$OH and OH radicals on ice dust which presented reaction 3, 4, and 5.

\begin{align}
\text{CH}_3\text{OH} + \text{OH} & \rightarrow \text{CH}_3\text{O} + \text{H}_2\text{O} \quad (3) \\
\text{CH}_3\text{O} + \text{CH}_2\text{OH} & \rightarrow \text{CH}_3\text{OCH}_2\text{OH} \quad (4) \\
\text{CH}_3\text{OCH}_2\text{OH} + \text{UV} & \rightarrow \text{CH}_3\text{OCHO} \quad (5)
\end{align}

Recently, Ahmad et al. (2020) proposed another pathway to the formation of methyl formate in hot molecular cores which works both in gas-phase and grain surface reaction with involving formaldehyde (H$_2$CO)

\begin{align}
\text{H}_2\text{CO} + \text{H}_2\text{CO} & \rightarrow \text{CH}_3\text{OCHO} \quad (6)
\end{align}

After the detection of C$_2$H$_5$CN and CH$_3$OCHO towards IRAS 18566+0408, we expect more complex molecular species would be observable from this hot molecular core region with other bands of ALMA. Since C$_2$H$_5$CN and CH$_3$OCHO were detected successfully in IRAS 18566+0408, we recommend a search of molecular transition lines of methanol (CH$_3$OH) and dimethyl ether (CH$_3$OCH$_3$) towards the hot molecular core region. We propose to study transition lines of complex molecule dimethyl ether in IRAS 18566+0408 because it was known as the precursor of CH$_3$OCHO in a cold environment (Bonfand et al. 2019). Methyl cyanide (CH$_3$CN), which is the precursor of ethyl cyanide (C$_2$H$_5$CN), was earlier detected towards IRAS 18566+0408 hot molecular core. The detection of the C$_2$H$_5$CN and CH$_3$OCHO with the multiple numbers of transitions encourages more detailed studies of other molecular species towards IRAS 18566+0408 to understand the chemical complexity.

5. Conclusion

We reported the first detection of the complex organic molecules ethyl cyanide (C$_2$H$_5$CN) and methyl formate (CH$_3$OCHO) towards the hot molecular core region IRAS 18566+0408. Our main findings in this work are summarized below

1. We successfully detected a total of three unblended strong rotational emission lines of ethyl cyanide (C$_2$H$_5$CN) and eight unblended rotational lines of methyl formate (CH$_3$OCHO)
towards IRAS 18566+0408 using ALMA. Additionally, we also detected the rotational emission lines of SO, CH$_2$CO, HC$_3$N, H$_2^{24}$CS, HC$^{13}$CCN, HCC$^{13}$CN, and CH$_3$CHO towards IRAS 18566+0408.

2. Using the rotational diagram method, the statistical column density of ethyl cyanide (C$_2$H$_5$CN) was $N$(C$_2$H$_5$CN) = $(3.50\pm0.68)\times10^{15}$ cm$^{-2}$ with rotational temperature $T_{rot} = 150\pm2.5$ K and the statistical column density of methyl formate (CH$_3$OCHO) was $N$(CH$_3$OCHO) = $(1.55\pm0.31)\times10^{16}$ cm$^{-2}$ with rotational temperature $T_{rot} = 150\pm2.8$ K. The estimated fractional abundance of ethyl cyanide and methyl formate in the high mass star-forming region IRAS 18566+0408 relative to H$_2$ was $1.66\times10^{-9}$ and $7.38\times10^{-9}$ where the column density of hydrogen was $2.1\times10^{24}$ cm$^{-2}$.

3. We compared the calculated column density of ethyl cyanide (C$_2$H$_5$CN) and methyl formate (CH$_3$OCHO) with other known hot molecular cores G31.41+0.31, Sgr B2 (N), and Orion KL. After the comparison, We found that the column density of C$_2$H$_5$CN and CH$_3$OCHO were small with respect to G31.41+0.31, Sgr B2 (N), and Orion KL.

4. We discussed the possible formation and destruction pathways of C$_2$H$_5$CN and CH$_3$OCHO towards IRAS 18566+0408 using UMIST 2012 astrochemistry chemical network. We showed that the complex molecule methyl formate (CH$_3$CN) may be the possible precursor of the ethyl cyanide (C$_2$H$_5$CN). In the case of methyl formate (CH$_3$OCHO), we presented different possible formation mechanisms towards IRAS 18566+0408 and claimed that dimethyl ether (CH$_3$OCH$_3$), methanol (CH$_3$OH), and formaldehyde (H$_2$CO) acted as a precursor of methyl formate (CH$_3$OCHO).

5. After the successful detection of C$_2$H$_5$CN and CH$_3$OCHO towards IRAS 18566+0408, a broader study was needed to search other molecular lines in the other frequency band of ALMA to understand the chemical complexity in this hot molecular core.

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Software: CASA (v5.1.0) (McMullin et al. 2007), CASSIS (Cassis Team At CESR/IRAP 2014)
Data availability

The data that support the plots within this paper and other findings of this study are available from the corresponding author upon reasonable request. The raw ALMA data are publicly available at https://almascience.nao.ac.jp/asax/ (project id: 2015.1.00369.S).

Conflicts of interest

The authors declare no conflict of interest.

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