RECENT TOPICS ON ORGANIC MATTERS IN SPACE THROUGH ASTRONOMICAL OBSERVATIONS

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(Abstract)

It is known that more than 140 interstellar and circumstellar molecules have so far been detected, mainly by means of the radio astronomy observations. Many organic molecules are also detected, including alcohols, ketons, ethers, aldehydes, and others, that are distributed from dark clouds and hot cores in the giant molecular clouds. It is believed that most of the organic molecules in space are synthesized through the grain surface reactions, and are evaporated from the grain surface when they are heated up by the UV radiation from nearby stars. On the other hand the recent claim on the detection of glycine have raised an important issue how difficult it is to confirm secure detection of weak spectra from less abundant organic molecules in the interstellar molecular cloud.

Recent topics regarding observations of organic molecules in the interstellar molecular clouds, including independent observations of glycine by the 45m radio telescope and a detection of amino acetonitrile (NH_2CH_2CN) that is a precursor to glycine.

(Keywords)
Astrochemistry, Astrobiology, Interstellar molecules, Line identification, Astronomical observations

1. Introduction

In recent years highly sensitive observations on interstellar molecules have been conducted by, e.g., the Greenbank Telescope (GBT) and the Nobeyama 45m telescope. Such observations provided lots of new insights on new species, molecular abundances, existence of organic species in a wide variety of objects, and so on. These will be the basis in understanding the interstellar chemistry.

Remarkable progress was made in observing large, complex organic species, e.g., glycolaldehyde, the simplest sugar [1] or glycine, the simplest α-amino acid [2], which may link to the understanding to the origin of life in the universe. However some observed spectra have weak signal intensities and these spectra are contaminated by other spectra, leading the debates that such observation results are plausible or not.

In this paper I will review several observations on organic molecules toward cold and dark clouds and star forming regions, and will discuss what are needed to verify a new identification in this era of crowded spectra.

2. Molecular Line Survey toward TMC-1

Cold dark interstellar clouds have been extensively studied as the formation sites of low-mass stars and planetary systems since their identification to the interstellar molecular clouds in 1970's. A variety of exotic chemical compounds found in molecular clouds, especially those containing carbon atoms, attracted strong interests in connection with the formation of planets and the origin of life in the universe. Recent radio and IR observations towards comets collected important evidence that comets, 4.6 billion year-old fossil bodies of the proto-solar-system nebula, keep molecular composition similar to that in cold dark clouds. Therefore, the chemical evolution in cold dark clouds is basically important as the initial process of interstellar matter evolution toward the planets, and, ultimately to life.

Kaifu et al. [3] published a molecular spectral line survey data toward a dark cloud, the cyanoplyyne peak of Taurus Molecular Cloud-1 (TMC-1), in the frequency range between 8.8 and 50 GHz (Figure 1), using the 45-m mm-wave telescope of the Nobeyama Radio Observatory [4]. They detected 414 lines from 38 molecules. Most of the molecules are linear carbon chain species and their derivatives, and there are only a few organic species such as CH_3OH, CH_3CHO, HCCCHO and CH_2CHCN. More saturated species, e.g., C_2H_5CN and $HCOOCH_3$, were not detected at all. According to their preliminary analysis [4], these species generally have less abundance than major linear carbon chain molecules such as HC_3N and CCS, and it would be possible to conclude that the organic species are not the main constituent in the cold and dark clouds.

Chemical reactions in dark clouds are not yet fully understood, and many unknown molecules might be synthesized in dark clouds. It is essential for understanding the chemical reactions in dark clouds,

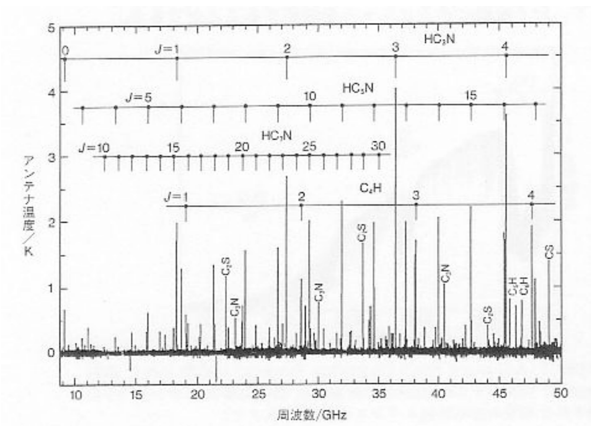

Figure 1. A compressed atlas of the 8.8-50 GHz spectrum toward TMC-1 (cyanopolyyne peak). The abscissa is the frequency in GHz, and the ordinate is the line intensity expressed in the temperature scale.

therefore, to make an unbiased frequency survey that can detect all molecular lines, including unpredicted lines of unknown molecules.

2. Detection of Organic Species in the Early Stage of Protostellar Evolution

So far large organic molecules (e.g., $HCOOCH_3$, $(CH_3)_2O$ and C_2H_5CN) were observed with high abundances toward the hot cores such as Orion KL, Sgr B2(N) and W51 e1/e2 where O/B stars are formed. Sgr B2 is a famous giant molecular cloud near the Galactic center, and is well-known for the high abundance of large organic molecules. There are several hot core sources within the Sgr B2 cloud (e.g., Sgr B2(M) and Sgr B2(N)), and Sgr B2(N) is known as the position of the highest abundance of organic molecules. Such highly saturated molecules are difficult to be produced by gas-phase chemical reactions under low-temperature conditions, and hence the grain surface chemistry is thought to play an important role in their production. When star formation takes place, the grain mantles are heated up by various activities of newly born stars, supplying parent molecules, like CH_3OH and H_2CO, into the gas phase through evaporation processes. Subsequent gas-phase reactions under high-temperature and high-density conditions would produce large organic molecules.

Recently detections of large organic species were reported toward the hot corinos in IRAS 16293-2422 [5-7]. Further detection of $HCOOCH_3$ toward NGC1333 IRAS4B [8] and NGC2264 MMS3 [9] were reported. Figure 2 shows the spectrum of $HCOOCH_3$ toward NGC1333 IRAS4B that is a class 0 low-mass protostar with an estimated age of a few 100 years. This suggests that the complex organic molecules appear from the very early stage of protostellar evolution.

Sakai et al [9] found the $HCOOCH_3$ distribution, reveald by the Nobeyama Millimeter Array, seems to be similar to the case of Orion KL Compact Ridge where the molecular peak is shifted from the dust continuum peak, and suggests that such distribution similarity would give a hint to understand the formation of $HCOOCH_3$ in hot corinos and hot cores.

Since other highly saturate organic species, such as C_2H_5OH, $(CH_3)_2O$ and C_2H_5CN, are observed in hot cores, it would be necessary to conduct deep observations on these species toward low-mass protostars to further understand the formation mechanism and evaporation conditions of organic species.

3. Recent Reports of Large Organic Species toward High Mass Star Forming Regions

In the last several years many very large organic molecules were reported to be detected. This is primarily because of the powerful observation performance of the Greenbank Telescope (GBT) together with improvement of the receiver sensitivities. These molecules include glycolaldehyde (CH_2OHCHO) [1], ethylene glycol ($(CH_2OH)_2$) [10], glycine (NH_2CH_2COOH) [2], propenal (CH_2CHCHO) and propanal (CH_3CH_2CHO) [11], acetone ($(CH_3)_2CO$) [12], cyanoallene (CH_2CCHCN) [13], acetamide (CH_3CONH_2) [14], and cyanoformaldehyde (CNCHO) [15].

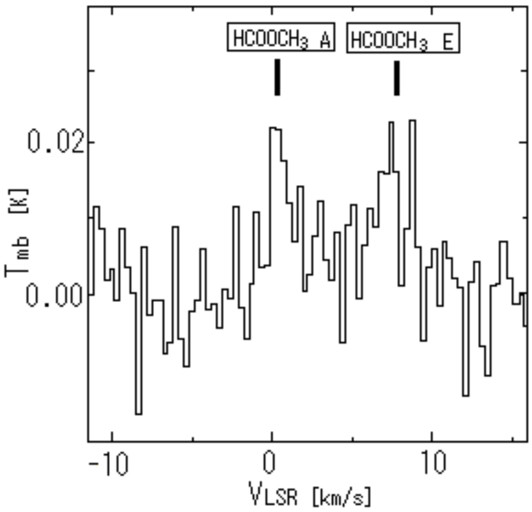

Figure 2. A Spectrum of $HCOOCH_3$ toward NGC1333 IRAS4B taken by the Nobeyama 45m Telescope. The abscissa is the radial velocity with respect to the local standard of rest (LSR), and the ordinate is the line intensity expressed in the temperature scale.

The report on the detection of glycolaldehyde [1] toward Sgr B2(N) by the Kitt peak 12m telescope was an epoch making one, because glycolaldehyde is the simplest sugar and really a prebiotic molecule. However the reported spectra had low signal to noise ratios, and some of them appeared on the shoulders of other molecular lines. Such a situation had led to debates if the detection was secure. In 2004 Hollis et al [16] made observations of glycolaldehyde by the GBT in four frequency ranges below 22 GHz, showing data with sufficient signal to noise ratios. Three transitions out of four showed absorption features at 63 kms^{-1} where absorption features from other already known species appear. The GBT observations made the detection of glycolaldehyde secure.

On the other hand the cases for propenal and ethylene glycol are different. Only two propenal lines were reported toward Sgr B2(N), and the absorption features at 63 kms^{-1} is apparent for only one line. Five ethylene glycol data were reported, however, they appeared on the shoulders of other molecular lines. This situation made difficult to investigate if the intensity distribution was reasonable for species observed toward Sgr B2(N). Therefore it may be concluded that the detection of propenal and ethylene glycol have not yet been confirmed.

4. Interstellar Glycine

The report on the detection of glycine [2], the simplest α-amino acid, had the similar situation in that the signal-to-noise ratios were not so high and many spectra seemed to be contaminated. They observed 27 frequency bands of glycine conformer I toward Orion KL, Sgr B2(N) and W51 e1/e2, however, only three of them were reported to be observed from three objects. Intensity analyses by means of the rotation diagram were made, and the distributions seemed plausible. However, the derived column densities of glycine for three sources had similar values, inconsistent with a fact that in most cases a column density of a molecule toward Sgr B2(N) is higher by about two order of magnitudes than those toward Orion KL and W51 e1/e2.

Therefore we made independent observations by the 45m telescope at Nobeyama. Because the glycine spectra had high possibility of contamination, we carefully examined our past observed data to find “clean spectrum windows” where no transitions from other known abundant species may exist.

Figure 3 shows a spectrum observed toward Orion KL at around 90 GHz. There are transitions of glycine conformer I at 90043.13 MHz ($15_{1,15}$-$14_{1,14}$, upper energy = 24.63 cm^{-1}), 90049.71 MHz ($15_{0,15}$-$14_{0,14}$, upper energy = 24.62 cm^{-1}), and 90056.98 MHz ($15_{1,15}$-$14_{0,14}$, upper energy = 24.63 cm^{-1}). The expected brightness temperatures for these transitions are around 20 mK when we used the column density and the rotation temperature derived by Kuan et al [2]. One peak coincides with the glycine transition at 90043.13 MHz, and showed expected intensity, however, other two are not clearly seen. The line at 90043.13 MHz was not identified when we investigated available molecular line databases, leaving a possibility that the line could be identified to the glycine line. However we noticed that there is another line next to the 90043.13 MHz line with similar line intensity. Such a “doublet line” could be due to the internal rotation, and it is well known that the molecular abundance of $HCOOCH_3$ toward Orion KL is so high. We contacted a laboratory molecular spectroscopist, Dr. Hitoshi Odashima at Toyama University, asking if he had measured weak lines of $HCOOCH_3$, and it was revealed that two unassigned lines of $HCOOCH_3$ matched the two lines above.

Therefore it can be concluded that the detection of interstellar glycine has not yet been confirmed.

5. Detection of Amino acetonitrile in Space

In relation with the origin of life, the question if there are amino acids in the interstellar space has attracted many researchers. As we have seen, all the attempts to detect the simplest amino acid, glycine, have been unsuccessful. Therefore there would be other approaches to study the possible existence of amino acids through searching for their precursors. As is well known the hydrolysis of amino acetonitrle (NH_2CH_2CN) will produce glycine.

In May 2008 a paper of the detection of amino acetonitirile was published [17]. The authors of the paper observed the Sgr B2(N) with the IRAM 30m radio telescope in Spain, using 88 millimeter-wave transitions of amino acetonitrile. A part of reported spectra is shown in Figure 4. Since it is well known that Sgr B2(N) shows so many lines from various interstellar molecules, that have wide line shape, the line contamination is a serious problem when detecting weak features. It is clearly seen in Figure 4 that the claimed spectra of amino acetonitrile have low signal-to-noise ratios, and are often overlapped by other spectral features.

Thus the authors utilized the IRAM interferometer and the Australian Telescope Compact Array (ATCA) to pick up signals from very compact sources, and succeeded to find that the amino acetontrile is confined within a very small (~2 seconds of arc) cores within Sgr B2(N). A radio interferometer consists of multiple radio telescopes that are separated with a distance but connected by data transmission cables. All the received signals are collected and processed by a correlator to produce synthesized images. The synthesized images are equivalent to those observed by a virtually large

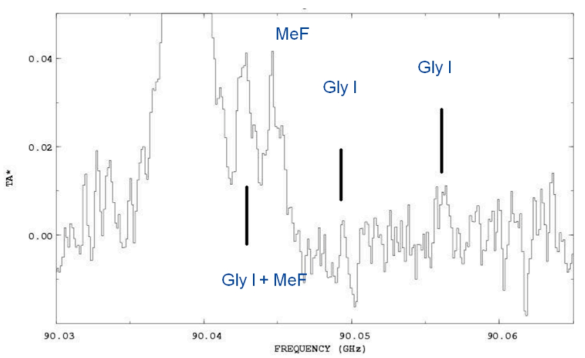

Figure 3. A Spectrum toward Orion KL at around 90 GHz where the Glycine (conformer I) transitions exist, that are shown by the vertical lines. The abscissa is the frequency in GHz, and the ordinate is the line intensity expressed in the temperature scale. MeF stands for $HCOOCH_3$.

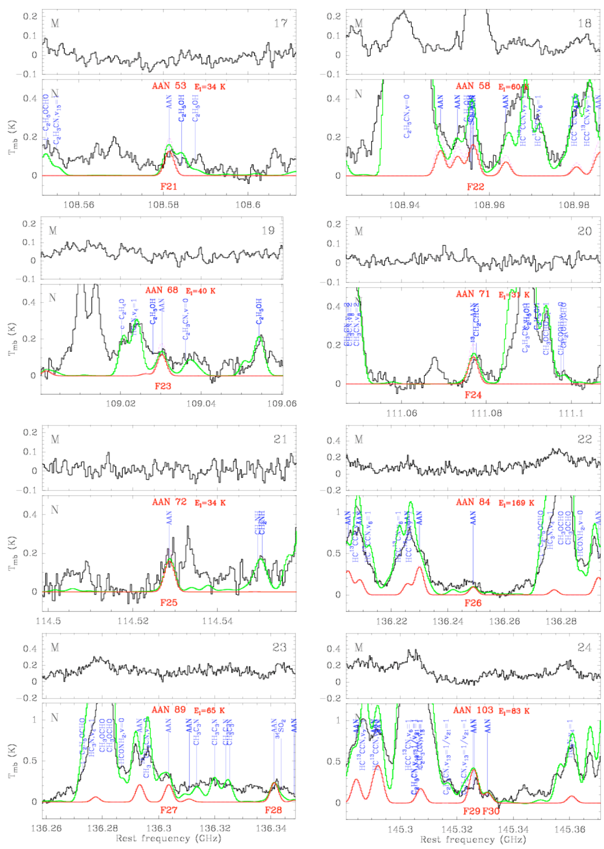

Figure 4. Sample spectra of amino acetonitrile (AAN) toward Sgr B2(N) observed by the IRAM 30m radio telescope, taken from Figure 1 of the original paper [17]. The lower plot shows in black the spectrum obtained toward Sgr B2(N) in main-beam temperature scale (K), while the upper plot shows the spectrum toward Sgr B2(M). The rest frequency axis is labeled in GHz. The lines identified in the Sgr B2(N) spectrum are labeled in blue. The top red label indicates the AAN transition centered in each plot, along with the energy of its lower level in K. The other AAN lines are labeled in blue only. The green spectrum shows the LTE model containing all identified molecules, including AAN [17]. The LTE synthetic spectrum of AAN alone is overlaid in red, and its opacity in dashed violet. All observed lines which have no counterpart in the green spectrum are still unidentified in Sgr B2(N).

radio telescope with a diameter of the maximum separation distance between the element telescopes. Therefore the interferometer can achieve very high spatial resolution. However it is less sensitive to extended sources larger than the field of view of the element telescope.

The derived column density of aceto aminonitrile is 2.8×10^{16} cm^{-2}. The volume density of molecular hydrogen is about 1.7×10^{8} cm^{-3}, and a mass of the core is about 2340 times the solar mass. Therefore an amino acetonitrile fractional abundance was calculated to be 2.2×10^{-9}, which is relatively high among known organic interstellar molecules.

The formation of amino acetonitrile itself was also investigated theoretically [18]. They found that water can efficiently catalyze a reaction between methylenimine CH_2NH and hydrogen isocyanide HNC to form amino acetonitrile in the grain mantles at a temperature of 50 K. Methylenimine was detected in the gas phase toward Sgr B2(N) [19]. An evidence was found for both hot, compact and cold, extended components and derived a column density of 3.3×10^{17} cm^{-2} for the compact component, with a source size of 2.7 seconds of arc [19], which is consistent with that value derived by Belloche et al.[17]. This column density is an order of magnitude larger than the column density for amino acetonitrile [17], which does not rule out methylenimine as a precursor of amino acetonitrile.

Since the lines of amino acetonitrile have low signal-to-noise ratios and are contaminated, it is crucial to observe other hot core sources to confirm interstellar amino acetonitrile as a direct precursor to glycine.

6. Conclusions

Recent high-sensitivity observations toward interstellar molecular clouds have revealed several new large organic molecules that would be related with the origin of life. However, it was found that the interstellar glycine has not been confirmed yet, and the next generation radio telescopes, such as the ALMA, would give a clue to search for life-related species. The report of detection of amino acetonitrile would be very encouraging to study the origin of life in the Universe.

In any case, careful observations with various points of view would be needed toward secure detections of prebiotic molecules in the interstellar space.

Acknowledgments

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