Abstract
At the Astrochemistry Focus Group, we discussed what is still missing in our understanding even with new knowledge given at this conference, and what can be done for that within 10 years from now. Still missing in understanding are UV-photons and cosmic-rays interactions with icy dust grains, Sulphur and Phosphorus chemistry, Metallicity effect, Duration (time) effect, COM formation and destruction, phase transition, dust-gas interface, dust evolution, etc. What we should do are multi-scale high spectral resolution molecular observations, laboratory work, theory, radiative transfer, etc. We need careful modeling without simplifying things. Next, I introduce our research on Planck cold clumps. We observed thirteen Planck cold clumps with the James Clerk Maxwell Telescope/SCUBA-2 and with the Nobeyama 45 m radio telescope. The N$_2$H$^+$ distribution obtained with the Nobeyama telescope is quite similar to SCUBA-2 dust distribution. The 82 GHz HC$_3$N, 82 GHz CCS, and 94 GHz CCS emission are often distributed differently with respect to the N$_2$H$^+$ emission. The CCS emission, which is known to be abundant in starless molecular cloud cores, is often very clumpy in the observed targets. We made deep single-pointing observations in DNC, HN$^+$, N$_2$D$^+$, cyclic C$_4$H$_2$ toward nine clumps. The detection rate of N$_2$D$^+$ is 50%. In two of the starless clumps observe, the CCS emission is distributed as it surrounds the N$_2$H$^+$ core (chemically evolved gas), which resembles the case of L1544, a prestellar core showing collapse. In addition, we detected both DNC and N$_2$D$^+$. These two clumps are most likely on the verge of star formation. We introduce the Chemical Evolution Factor (CEF) for starless cores to describe the chemical evolutionary stage, and analyze the observed Planck cold clumps.

1. Summary of Discussion at the Astrochemistry Focus Group

1.1. Goal

Astrochemistry Focus Group wished to make clear what is still missing in our understanding even with new knowledge given at this conference. The purpose is to have an idea on what can be done for that, say, within 10 years from now.

1.2. Individual Comments

Paola Caselli said “still missing things in the field of astrochemistry are good understanding of the dust-gas interface, dust evolution, UV-photons and cosmic-rays interactions with icy dust grains. Multi-scale high spectral resolution molecular observations, laboratory work, theory, and radiative transfer are needed.” Alvaro Sanchez-Monge said “Carbon, Oxygen, Nitrogen chemistry is well understood... the next elements for which the chemistry still needs improvement will (probably) be Sulphur and Phosphorus.”

Next we discussed the environmental effect. Nami Sakai said “Chemical diversity in YSO would originate from differences in time after the UV shielding of the molecular cloud (i.e. period in starless phase in each source). Then, what can make the time difference?” Yuri Nishimura said “We need to be more aware of the effect of metallicity, that is, the amount of dust grains and UV-shielding.” Takashi Shimonishi said “Comprehensive understanding of gas-grain chemistry as a function of galactic metallicities is needed. Statistical observations of ices and molecular gas around high- and low-mass YSOs in Local Group galaxies (LMC, SMC, IC10, M51, etc.) are important. Also, I am interested in astrochemistry as a function of redshift.”

Kotomi Taniguchi pointed out that the chemical evolution and mechanisms in high-mass star forming regions should be explored. Kuo-Song Wang said that he wants to know “How complex molecules, especially those closely related to astrobiology, form, survive, and destroy during the star/planet formation processes?”

Alvaro Sanchez-Monge is concerned “How COMs are produced? Grain-surface vs gas-phase reactions. Are COMs expected to be found everywhere? (cold vs hot environments, low-mass vs high-mass dense cores, is the non-detection of COMs just a matter of sensitivity?)” Gwendoline Stéphan pointed out that a better understanding of the formation routes of complex chemistry like hydrocarbons and COMs is required, whatever the regions. Nguyen Hoang Phuong Thanh is concerned how to determine clearly about the chemical origin of CO and N$_2$ differential depletion in prestellar core. Yoko Okada asked “Why is the line profile of the [CII] emission different from that of the CO and...”
To characterize Planck cold clumps, it is essential to understand the initial conditions of molecular clouds as the Planck Cold Clump Collaboration in order to understand the initial conditions of star formation (Liu, 2015). Planck cold clumps, for which we have already obtained accurate positions from preliminary IRAM 30m observations in N$_2$H$^+$ and/or SCUBA-2 observations.

2. Introduction to Research on Planck Cold Clumps

2.1. Introduction

On the basis of the Planck all-sky survey (Planck 2011, 2015), we are carrying out a series of observations of molecular clouds as the Planck Cold Clump collaboration in order to understand the initial conditions for star formation (Liu, 2015). Planck cold clumps have low dust temperatures (10–20 K; median=14.5 K). Pilot observations have been carried out with various ground-based telescopes such as JCMT, IRAM, PMO 14m, APEX, Mopra, Effelsberg, CSO, and SMA (Liu, 2015). A Large Program for JCMT dust continuum observations with SCUBA-2 (SCOPE) and a Key Science Program with TRAO 14 m radio telescope (TOP) are ongoing.

To characterize Planck cold clumps, it is essential to investigate their chemical and physical properties in detail. In particular, we try to make their evolutionary stages clear. The chemical evolution of molecular clouds has been established to some extent, not only for nearby dark clouds (e.g., Suzuki, 1992; Hirota, 1992; Benson, 1998; Hirota, 2006; 2009), but also for giant molecular clouds (GMCs; Orton A GMC Tatematsu, 2010; 2011; Ohashi, 2014): Vela C GMC (Ohashi, 2010); Infrared Dark Clouds (Sanhueza, 2012; Hoq, 2013). Carbon-chain molecules such as CCS and HC$_3$N tend to be abundant in starless molecular cloud cores, while N-bearing molecules such as NH$_3$ and N$_2$H$^+$ as well as c-C$_3$H$_2$ tend to be abundant in star-forming molecular cloud cores. Furthermore, deuterium fractionation ratios are powerful evolutionary tracers (Hirota, 2006; Sakai, 2012). We investigate the evolutionary stages of Planck cold clumps using molecular column density ratios. For this purpose, by using the Nobeyama 45 m telescope, we observed 13 Planck cold clumps, for which we have already obtained accurate positions from preliminary IRAM 30m observations in N$_2$H$^+$ and/or SCUBA-2 observations.

2.2. Observations

Observations with the 15 m James Clerk Maxwell Telescope (JCMT) on Mauna Kea were made between 2014 November and 2015 December in the pilot survey phase (project IDs: M15AI05, M15BI061) of the JCMT legacy survey program “SCOPE”. SCUBA-2 was employed for observations of the 850 $\mu$m continuum. It is a 10,000 pixel bolometer camera operating simultaneously at 450 and 850 $\mu$m. The beam size of SCUBA-2 at 850 $\mu$m is $\sim$14$''$. The typical rms noise level of the maps is about 6-10 mJy beam$^{-1}$ in the central 3$'$ area, and increases to 10-30 mJy beam$^{-1}$ out to 12$''$. The data were reduced using SMURF in the STARLINK package.

Observations with the 45 m radio telescope of Nobeyama Radio Observatory$^4$ were carried out from 2015 December to 2016 February. Observations with the receiver TZ1 (we used one beam called TZ1 out of two beams of the receiver TZ) Asayama, 2013; Nakajima, 2013 were made to simultaneously observe four molecular lines, 82 GHz CCS, 94 GHz CCS, HC$_3$N and N$_2$H$^+$. Observations were carried out with T70 to simultaneously observe four other lines, HN$^13$C, DNC, N$_2$D$^+$, and cyclic C$_3$H$_2$. TZ1 and T70 are double-polarization, two-sideband SIS receivers. The FWHM beam sizes at 86 GHz with TZ1 and T70 were

$^1$http://www.eaoobservatory.org/jcmt/science/large-programs/scope/

$^2$http://radio.kasi.re.kr/trao/key_science.php

$^4$Nobeyama Radio Observatory is a branch of the National Astronomical Observatory of Japan, National Institutes of Natural Sciences.
2.3. Results

$\text{N}_2\text{H}^+$ was detected for all sources, and we detected 81 GHz CCS from seven out of 13. We show examples of the molecular line intensity distribution shown in Figures 1 and 2. In general, the $\text{N}_2\text{H}^+$ distribution (black contours in panel (b)) is quite similar to the 850 $\mu$m dust continuum emission distribution (contours in panel (a); gray-scale in panels (b) and (c)). The 82 GHz CCS emission (blue contours) is clumpy in general, and is often located at the edge of the $\text{N}_2\text{H}^+/850$ $\mu$m core or is distributed as it surrounds the $\text{N}_2\text{H}^+/850$ $\mu$m core. Most clumps are as cold as 10–20 K, and therefore the depletion of CCS can contribute to a configuration of the $\text{N}_2\text{H}^+$ core being surrounded by CCS ($\text{Aikawa, 2001}$, $\text{Bergin, 2002}$).

2.4. Discussion

Hirota and Yamamoto ($\text{Hirota, 2006}$) indicated the evolutionary sequence of starless cores by using column density ratios such as $N$(DNC)/$N$(HN$^{13}$C). We introduce a new parameter to represent the chemical evolution by using molecular column density ratios, the chemical evolution factor (CEF). We define
CEF so that starless cores have CEFs of ~ -100 to 0, and star-forming cores show ~ 0 to 100. Starless cores having CEF ~ 0 are regarded as being on the verge of star formation. By taking into account the observational results (Suzuki 1992; Crapsi 2005; Hirota 2006; Tatematsu 2011), we define CEF as $CEF = \log\left(\frac{N(N_2H^+)\times N(CCS)}{2.5}\right)\times 50$, $\log\left(\frac{N(DNC)}{N(HN_13C)}\right)\times 120$, $\log\left(\frac{N(N_2D^+)}{N(N_2H^+)}\right)\times 0.3\times 50$, and $\log\left(\frac{N(NH_3)}{N(CCS)}\times 70\right)\times 70$, for starless cores with $T_k \sim 10-20$ K at a spatial resolution of order 0.015–0.05 pc (for 0.1-pc sized structure “molecular cloud core”). Figure 3 shows the resulting CEF using the data in the literature (Crapsi 2005; Hirota 2006; 2009). Figures 4 and 5 show the CEFs estimated in the present study. To see the effect of very different spatial resolution (and probably very different volume density and very different beam-filling factor), we show sources located beyond 1 kpc in parentheses. In this paper we treat only starless cores for CEF, because evolution of star-forming cores has not well been characterized yet.

Next, we investigate the morphology. In G089.9-01.9, the 82 GHz and 94 GHz CCS emission (young molecular gas) is distributed as if it surrounds the $N_2H^+$ core (evolved gas). In G157.6-12.2, the 82 GHz CCS emission is distributed as if it surrounds the $N_2H^+$ core. Such configurations were previously reported in L1544 (Aikawa 2001), and also starless NH$_3$ core surrounded by CCS configurations are also observed in L1498 (Lai

Figure 3. Chemical Evolution Factor (CEF) for starless sources in the literature.

Figure 4. Chemical Evolution Factor (CEF) for starless SCUBA-2 peaks based on the column density ratio of $N(N_2H^+)/N(CCS)$. The source name in parentheses means distance is larger than 1kpc.

Figure 5. Chemical Evolution Factor (CEF) at starless T70 positions based on multiple column density ratios. The source name in parentheses means distance is larger than 1kpc.
and Orion A GMC (Tatematsu 2014). L1544 shows evidence of the prestellar collapse. Therefore, these cores could be good targets for further studies for the initial conditions of star formation. For G157.6-12.2, CEF is $\sim 0$, and its linewidth is as narrow as 0.3 km s$^{-1}$. It is possible that this core is a coherent core that has largely dissipated turbulence, and is on the verge of star formation (Tatematsu, 2014; Ohashi, 2016).

The details are reported in (Tatematsu, 2017).

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