

INTERSTELLAR CHEMISTRY IN ORION KL

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ABSTRACT A map of SiO ($J = 2 - 1$) in Ori KL has been obtained with $2.8''$ spatial resolution by using Nobeyama Millimeter Array. The distribution of SiO evidences an interaction between outflow and dense gas around IRC4 and IRC5; these infrared sources are thus considered to be shock-heated regions. Since distributions of $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 have a peak at the IRC5 position, such shock heating seems to play an important role in production of these molecules. Detection of CH_3OD around the interacting region most likely suggests that CH_3OH is evaporating from dust grains. $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 may be produced by gas-phase reactions starting from injected CH_3OH , or they might be evaporated from dust grains.

INTRODUCTION

Orion KL is a nearby massive-star-forming region, and has extensively been studied with interest on interstellar chemistry as well as star-formation processes. Single-dish observations indicated that the Ori KL region is composed of several components whose physical and chemical conditions are significantly different from one another (e.g. Blake et al. 1987). They are an *extended ridge*, a *hot core*, a *plateau source*, a *compact ridge*, and so on. Since about 10 years ago, high resolution maps of various molecules in Ori KL have been obtained with millimeter interferometers (e.g. Wright et al. 1983; Masson and Mundy 1988; Plambeck and Wright 1988; Murata 1990). These observations clarified detailed spatial distribution of each component mentioned above, and indicated strong inhomogeneity in chemical composition. Although such chemical inhomogeneity seems to be deeply related to star-formation activities, chemical processes occurring in each component are not well understood at present. In this paper, we present our recent results on Ori KL chemistry obtained with Nobeyama Millimeter Array (NMA), and discuss a relation between star-formation processes and chemical processes in this region.

INTERACTION BETWEEN OUTFLOW AND DENSE GAS: SiO OBSERVATIONS

The spectral lines of SiO are very broad in Ori KL, indicating that SiO mainly exists in outflowing gas from IRC2. The distribution of SiO in Ori KL was first studied by Wright et al. (1983) with resolution of $6''$ by using the Hat Creek interferometer. Although they demonstrated the bipolar nature of the outflow from IRC2, a distribution of the outflowing gas in the vicinity of IRC2 was not well resolved. Since the outflow most likely plays an important role in physical and chemical processes in this region, we obtained a high resolution ($2.8''$) map of SiO ($J = 2 - 1$) with NMA. Figure 1 shows a map of the central velocity component ($-4 < v < 20 \text{ km s}^{-1}$) superposed on the 3 mm continuum map (Murata et al. 1992) and the $20 \mu\text{m}$ continuum map (Downes et al. 1981).

The distribution of SiO in Figure 1 consists of two components, an unresolved component which associates with IRC2 and an extended component. The extended component clearly avoids the 3 mm continuum peaks C and D, suggesting possible interaction between outflow and the dense clumps. In fact, groups of OH masers are found in the interacting regions. Furthermore, the 20 μm continuum is very bright there. Particularly, IRC4 and IRC5 trace the eastern edge of the 3 mm continuum peak C, and they are between the outflow and the dense clumps. Recently Murata (1990) studied the CS ($J = 2 - 1$) line with NMA. They found an expanding motion around IRC4 on the position-velocity diagram; the outflow is certainly colliding with the dense clumps. Moreover, detection of the vibrationally excited methanol at the IRC4 position indicates that the gas is considerably heated up in this region (Mikami et al. 1992). All these results established that IRC4 and IRC5 are shocked heated regions caused by the interaction between the outflowing materials and dense clumps. This interaction seems to be related to the efficient production of dimethylether ($(\text{CH}_3)_2\text{O}$) and methylformate (HCOOCH_3), as discussed below.

DISTRIBUTION OF $(\text{CH}_3)_2\text{O}$ AND HCOOCH_3

One of the most characteristic features in the Ori KL chemistry is existence of oxygen containing organic molecules like $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 . These two molecules have been considered to exist in a *compact ridge* part of Orion KL. However, the physical and chemical properties of the *compact ridge* have been poorly understood. We therefore studied the distributions of $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 with NMA.

Figure 2 shows the total integrated intensity map of the $(\text{CH}_3)_2\text{O}$ ($7_{17}-6_{06}\text{EE}$) line at 147 GHz (Mikami et al. 1992). A synthesized beam is about $5'' \times 4''$. When the distribution of $(\text{CH}_3)_2\text{O}$ is compared with that of the 20 μm continuum, it is found that the $(\text{CH}_3)_2\text{O}$ distribution has a peak at the interacting region around IRC4 and IRC5. Furthermore there is a small peak near the IRC3 position. We also observed HCOOCH_3 ($12_{3,10} - 11_{3,9}\text{A}$) (Mikami et al. 1992), and found that its distribution is very similar to that of $(\text{CH}_3)_2\text{O}$. Recently, these two molecules are independently studied by Minh and Ohishi (1992), and their maps are almost consistent with ours.

The above results suggest that the productions of $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 are possibly related to the interaction occurring in the interface between the outflow and the dense gas. These two molecules seem to be produced by gas phase shock chemistry or shock evaporation of grain mantles. Which of these two processes is then more important? An answer to this question comes from an interferometric observation of CH_3OD by Saito et al. (1992).

PRODUCTION MECHANISM OF $(\text{CH}_3)_2\text{O}$ AND HCOOCH_3

Saito et al. (1992) studied the distribution of the CH_3OD in Ori KL with NMA. They found that it has a peak at the interacting region around IRC4 and IRC5. This result is surprising, because deuterium fractionation in a molecule can never occur in the high temperature conditions (~ 150 K) observed in the interacting region. Since the deuterium fractionation only occurs at low temperature (~ 10 K), existence of CH_3OD in the interacting region can only be explained by evaporation of CH_3OD from grain mantles.

When the cloud is still cold before star formation, the deuterium atom is abundant in gas phase. This is because the hydrogen and deuterium atoms are mainly produced through dissociative recombination reactions of various molecular ions

in which high deuterium fractionation occurs. Accordingly, the deuterium atom is expected to be abundant on a grain surface. If CH_3OH is produced on grain mantles, CH_3OD is also produced with high abundance. After the onset of star formation, CH_3OH evaporates from dust grains. This mechanism explains the high abundance of CH_3OD even in high temperature regions. Therefore CH_3OD represents a *fossil* molecule produced on a dust grain in the cold cloud phase. Such a mechanism of the deuterium fractionation was first proposed by Tielens (1983), and was observationally confirmed by Walmsley et al. (1987). The detection of CH_3OD at the interacting region indicates that CH_3OH mainly comes from dust grains due to shock heating.

Once CH_3OH is injected into gas phase, $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 are produced from CH_3OH through various gas-phase reactions proposed by Millar et al. (1991). Alternatively, these two molecules might be produced directly on dust grains. In either case, the distribution of $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 around the interacting region can be explained.

SUMMARY

From all the results mentioned above, we can conclude that the *compact ridge* chemistry producing $(\text{CH}_3)_2\text{O}$ and HCOOCH_3 is possibly related to the interaction between outflow and dense clumps around IRC4 and IRC5. It is likely that the evaporation of grain mantles plays an important role in the production of these molecules. High angular resolution ($< 3''$) observations of various molecules would lead us to further understanding of a link between the physical and chemical processes in Ori KL.

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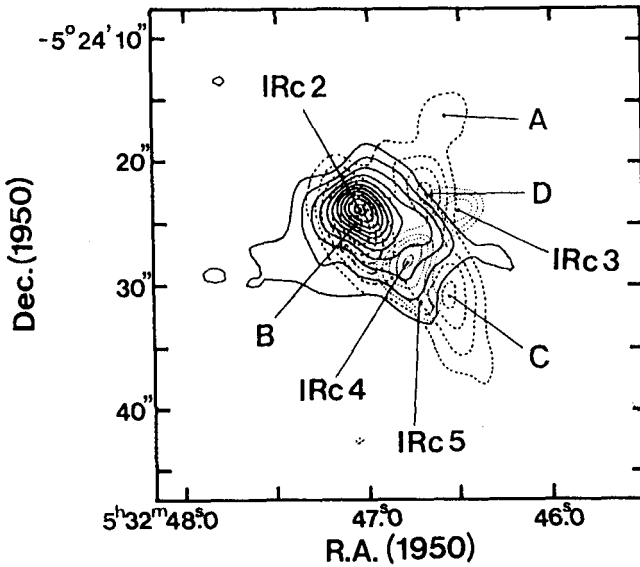


Figure 1: Map of SiO ($J = 2 - 1$) in the velocity range of $-4 < v < 20 \text{ km s}^{-1}$. The lowest contour and the contour interval are 4σ . The peak flux is 16 Jy beam^{-1} . Dashed contours represent the distribution of 3 mm continuum (Murata et al. 1992), and dotted contours the distribution of $20 \mu\text{m}$ continuum around IRc3, IRc4, and IRc5 (Downes et al. 1981).

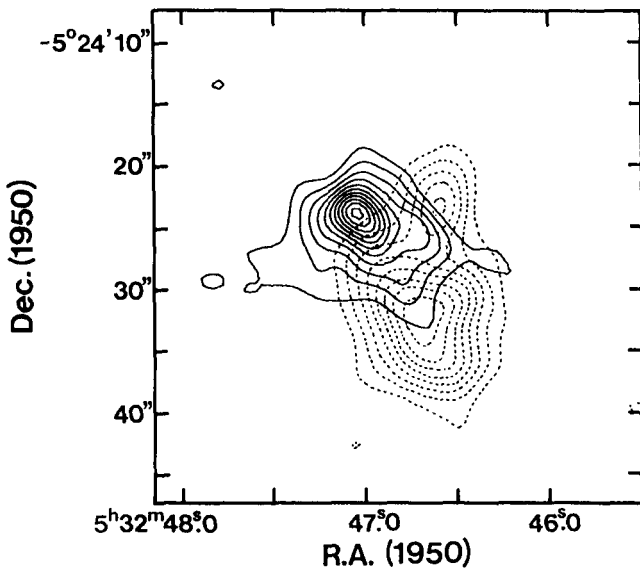


Figure 2: Total integrated intensity map of $(\text{CH}_3)_2\text{O}$ ($7_{17} - 6_{06} \text{ EE}$) superposed on the SiO map. The peak flux is 8.4 Jy beam^{-1} .

Biegging: Can the shock velocity be constrained by the requirement that grain mantles are evaporated without destroying the observed deuterated species like water, ammonia, and methanol?

Yamamoto: In principle yes. Since the dissociation energy of a molecule is larger than the desorption energy, grain mantles can be evaporated even by non-dissociative shock to some extent. But it seems difficult to estimate upper limit of non-dissociative shock velocity quantitatively.

Ohishi: As I have shown in our poster (Minh and Ohishi), high energy CH_3OH (330 K) seems to originate from the grain mantles around IRc2. The column density of CH_3OH is enough to produce observed amounts of HCOOCH_3 and $(\text{CH}_3)_2\text{O}$. We believe that the key-point to investigate the source of CH_3OH for the compact ridge is to observe by using high-energy transitions of oxygen-containing organic molecules.

Yamamoto: Certainly it is important to determine the column density distribution rather than the intensity distribution. According to single dish observations, the CH_3OH abundance in the *hot core* is much lower than that in the *compact ridge*.

Ho: Twenty years ago, people worked on grain chemistry, but then they gave up. Are people calculating for real abundances and so on?

Yamamoto: Gas phase chemistry almost explains dark cloud chemistry. In star forming regions, evaporation of grain mantles seems to play important roles, as I mentioned. Detailed understanding of relations between star formation activities and chemical composition is a future problem.