

OBSERVATIONS OF “HOT CORES”

MASATOSHI OHISHI

Nobeyama Radio Observatory

Nobeyama, Minamimaki, Minamisaku

Nagano, 384-13 Japan

Abstract. Recent observational results toward the “Hot Core” sources (Orion KL, SgrB2, G34.3+0.15, W51, and so on) are summarized. Several saturated organic molecules are commonly observed among these sources, and these results favor formations on the grain mantles followed by evaporation. Some results of surveys in “hot core molecules” are presented. Such molecules may be used as diagnostics to establish the presence of “hot core” regions.

1. Introduction

Molecules so far detected (Table 1) have provided us a lot of probes to investigate physical and chemical processes which take place in molecular and circumstellar clouds. Understanding the star formation processes is one of the important themes in astronomy, and molecular line observations, especially high spatial resolution observations, have given us quite interesting information related with star formation. Young stars which are formed in dense molecular cloud cores, heat up their surrounding materials and this gives rise to observable amounts of molecular emission lines. The molecular lines from such “Hot Core” regions are used to derive physical parameters, such as temperatures and densities, and study chemical processes.

Recent high spatial resolution millimeter and submillimeter-wave observations toward hot cores have revealed that their diameters are roughly 0.1 pc or less, temperatures are at least 100 K, number densities of molecular hydrogen are 10^5 to 10^8 cm^{-3} , and that they contain a few to a thousand of solar masses of gas. Hot Cores are usually associated with ultra-compact HII regions, and it seems likely that hot cores are dense gas clumps which have been left over from the star formation process and which are being

TABLE 1. Observed Interstellar Molecules as of August, 1996

Simple Hydrides, Oxides, Sulfides, Halogens and related molecules

H ₂ (IR)	CO	NH ₃	CS	NaCl*
HCl	SiO	SiH ₄ (IR)	SiS	AlCl*
H ₂ O	SO ₂	C ₂ (IR)	H ₂ S	KCl*
N ₂ O	OCS	CH ₄ (IR)	PN	AlF*

Nitriles and Acetylene derivatives

C ₃ (IR, UV)	HCN	CH ₃ CN	HNC	C ₂ H ₄ ⁺ (IR)
C ₅ ⁺ (IR)	HC ₃ N	CH ₃ C ₃ N	HNCO	C ₂ H ₂ (IR)
C ₃ O	HC ₅ N	CH ₃ C ₅ N ?	HNCS	
C ₃ S	HC ₇ N	CH ₃ C ₂ H	HNCCC	
C ₄ Si*	HC ₉ N	CH ₃ C ₄ H	CH ₃ NC	
	HC ₂ CHO	CH ₃ CH ₂ CN	HCCNC	
		CH ₂ CHCN		

Aldehydes, Alcohols, Ethers, Ketones, Amides and related molecules

H ₂ CO	CH ₃ OH	HCOOH	CH ₂ NH	CH ₂ CC
H ₂ CS	CH ₃ CH ₂ OH	HCOOCH ₃	CH ₃ NH ₂	CH ₂ CCC
CH ₃ CHO	CH ₃ SH	(CH ₃) ₂ O	NH ₂ CN	
NH ₂ CHO	(CH ₃) ₂ CO	H ₂ CCO		

Cyclic Molecules

C ₃ H ₂	SiC ₂	c-C ₃ H
-------------------------------	------------------	--------------------

Molecular Ions

CH ⁺ (OPT)	HCO ⁺	HCNH ⁺	H ₃ O ⁺	HN ₂ ⁺
HCS ⁺	HOCO ⁺	HC ₃ NH ⁺	HOC ⁺	H ₃ ⁺ (IR)
CO ⁺	H ₂ COH ⁺	SO ⁺		

Radicals

OH	C ₂ H	CN	C ₂ O	C ₂ S
CH	C ₃ H	C ₃ N	NO	NS
CH ₂	C ₄ H	HCCN*	SO	SiC*
NH (UV)	C ₅ H	CH ₂ CN	HCO	SiN*
NH ₂	C ₆ H	CH ₂ N	MgNC	CP*
HNO	C ₈ H	NaCN	MgCN	

Molecules observed in other frequency regions than radio are indicated in parentheses :
IR - infrared, OPT - optical and UV - ultraviolet.

* detected only in the envelope around the evolved star IRC+10216.

? claimed but not yet confirmed.

heated by embedded massive O and B stars that have just formed. The O and B stars' radiation clears up their surroundings and produces the ultra-compact HII regions, and very energetic stellar winds interact with the cores. Such interactions heat up not only the gas but also dust grains which coexist in the molecular gas. The dust temperatures in the hot cores close to the newly formed stars are high enough to evaporate mantles off the dust grains. This means that observations toward hot cores have the possibility to determine the mantle composition on the basis of the observed molecular abundances.

In these regions ammonia (NH_3) has very high column densities of more than 10^{18} cm^{-2} over the size of the core (Walmsley & Schilke, 1993). Such a high column density of NH_3 is believed to be a result of evaporation of grain mantles, but recent ISO observations have resulted in negative detections of NH_3 in grain mantles (see, for example, Tielens & Whittet in this volume). This recalls the question of the origin of the high NH_3 abundances. In spite of such a discrepancy, other saturated molecules (alcohols, ethers, and so on) are found to exist in hot cores in the last few years, and formation of these molecules on grain mantles followed by evaporation is favored by comparison of abundances obtained from observations and model calculations.

In this review I will to summarize what is known observationally in the Orion KL region, the best studied source in hot cores, in Sgr B2(N), a hot core in the Galactic Center region, and in other hot cores. Finally I will discuss what we should do in the future.

2. The Orion KL region

The Orion KL region is one of the best investigated objects in our Galaxy. There are two hot core sources: the Orion Hot Core and the compact ridge.

The Orion Hot Core has been previously reviewed by Genzel & Stutzki (1989), Wilson & Walmsley (1989), and Walmsley & Schilke (1993). It was discovered in the middle of 1970s, and several high excitation molecular line observations showed that there is a velocity component with $V_{\text{LSR}} \sim 6 \text{ km s}^{-1}$ and $\Delta V \sim 10\text{--}20 \text{ km s}^{-1}$ in the direction of the infrared cluster. Morris et al. (1980) observed several NH_3 transitions and concluded that the gas responsible for the emission was very hot ($> 220 \text{ K}$) and very dense ($n(\text{H}_2) \sim 5 \times 10^7 \text{ cm}^{-3}$). The diameter of the region was found to be only a few arcseconds and the region peaks at IRc2. These were verified by several VLA observations (Genzel et al. 1982, Pauls et al. 1983, Hermsen et al. 1988, Miggenes et al. 1989). Infrared polarization observations (Werner et al., 1983) suggested that only IRc2 and the BN object are self-luminous and other infrared sources may just be artefacts caused by scattering of the

radiation from IRc2. In this case, only IRc2 is responsible for the heating of the Orion Hot Core.

The molecular composition in the Orion Hot Core is quite different from that in its surrounding quiescent gas. It was found first that NH_3 and some nitrogen-containing molecules were enhanced. Genzel et al. (1982) analyzed the relative intensities of the hyperfine satellites of the NH_3 lines and derived that the column density of NH_3 in the Orion Hot Core was $\sim 5 \times 10^{18} \text{ cm}^{-2}$ and the inferred ratio $[\text{NH}_3]/[\text{H}_2]$ was $\sim 10^{-5} - 10^{-6}$, i.e., two to three orders of magnitude higher than the ratio in typical molecular clouds. Because gas phase reactions cannot reproduce such a high abundance of NH_3 , Genzel et al. speculated that it was the result of evaporation of grain mantles. Other than NH_3 , several CN-bond-containing molecules (HCN , HNC , HC_3N , CH_3CN , CH_2CHCN , $\text{CH}_3\text{CH}_2\text{CN}$) are known to be enhanced in the region (Blake et al. 1987, Irvine et al. 1987). The enhancement of HC_3N may be explained by a neutral-neutral reaction between C_2H_2 and CN . The high abundances of CH_2CHCN and $\text{CH}_3\text{CH}_2\text{CN}$ could be results of hydrogenation of HC_3N which adsorbed onto the grain surface before IRc2 heated up the region, followed by evaporation from the surface. But the interpretation for HCN and HNC is not so clear. Other enhanced species are SO (Plambeck et al., 1982), SO_2 , SiO (Wright et al., 1995), H_2S (Blake et al., 1987), HDO (Plambeck & Wright, 1987).

Another hot core in the Orion KL region, the compact ridge is located about $10''$ southwest of IRc2 and clearly shows different kinematic characteristics from those of the Hot Core; its radial velocity is $\sim 8 \text{ km s}^{-1}$ and $\Delta V = 3-4 \text{ km s}^{-1}$. These parameters are very similar to those in the more extended Orion ridge gas. However molecular lines observed toward the compact ridge appear to be hotter ($\sim 150 \text{ K}$) and denser than the extended ridge gas. The molecular composition of the compact ridge is well characterized by the enhancement of saturated oxygen-containing molecules, such as CH_3OH , HCOOCH_3 , and $(\text{CH}_3)_2\text{O}$. Interferometric observations using the Nobeyama Millimeter Array (Minh et al., 1993) clearly show that these species peak about $10''$ southwest of IRc2. Recent detection and mapping observations of $\text{CH}_3\text{CH}_2\text{OH}$ (Ohishi et al., 1995) show that its emissions arise from the compact ridge as well. Because gas phase model calculations cannot produce the observed amount of alcohols, these results favor that most of the alcohols form on the grain surface and evaporate. This idea is strongly supported by the interferometric mapping observations of CH_3OD (Saito et al., 1994). The CH_3OD peaks at the interaction region around IRc4 and IRc5. The ratio $[\text{CH}_3\text{OD}]/[\text{CH}_3\text{OH}]$ was reported to be $0.01 - 0.06$ (Mauersberger et al., 1988). Such deuterium fractionation in a molecule can never occur in the high temperature condition and can occur only at low temperature ($\sim 10 \text{ K}$). Therefore the existence of CH_3OD

in the interacting region can only be explained by evaporation from grain mantles.

Deuterated species are also observed toward the Orion Hot Core : NH_2D (Walmsley et al. 1987, Turner 1990), D_2CO (Turner, 1990), CH_2DCN (Gerin et al., 1992). These observations suggest enhancements of deuterium by a factor of roughly a thousand and formation of these species on grain surface before the Hot Core was heated up by $\text{Irc}2$.

Then how can we explain such different molecular compositions between the Orion Hot Core and the compact ridge ? The chemistry in hot cores was reviewed by Millar (1993) and by Millar in this volume. Brown et al. (1988) considered an isothermal collapse of a cold sphere of gas and computed the molecular composition in the gas to simulate the chemistry in the Orion Hot Core. On the other hand, Blake et al. (1987) presented a model to explain the high abundance of oxygen-containing molecules in the compact ridge. They proposed a chemical model in which the injection of large quantities of water would lead to methanol formation via radiative association, $\text{CH}_3^+ + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{OH}_2^+ + h\nu$ followed by dissociative recombination with electrons. Further, they suggested that the reactions of CH_3OH_2^+ with H_2CO and CH_3OH produced HCOOCH_3 and $(\text{CH}_3)_2\text{O}$, respectively. Millar et al. (1991) produced a detailed time-dependent chemical network based on this scheme, and showed that the injection of water could not explain the observed amount of oxygen-containing molecules. Instead they showed that CH_3OH injection leads to good agreement between observations and theoretical calculations. Based on these works Caselli et al. (1993) explained that the chemical differentiation between the Orion Hot Core and the compact ridge was the result of the thermal history during the gravitational collapse of a molecular cloud core where these two sources were born.

3. Sgr B2 region

Sgr B2 is a huge molecular cloud / HII region complex in the Galactic Center. There are a few active regions which contain several ultra-compact HII regions: Sgr B2(OH), Sgr B2(M) and Sgr B2(N). Sgr B2(OH) was mainly observed in 1970s and early 1980s and was thought as the activity center of Sgr B2. The thermal radio continuum sources, MD5 and MD4 (Martin & Downes, 1972), were referred as Sgr B2(M) and Sgr B2(N) by Martín-Pintado et al. (1990) for the first time. Goldsmith et al. (1987) carried out a detailed study around these regions using the 45m radio telescope of the Nobeyama Radio Observatory and found that HNCO and vibrationally excited HC_3N are only observed in a small region around the Sgr B2(N) clump. Vogel et al. (1987) used the VLA to produce maps of Sgr B2 in six

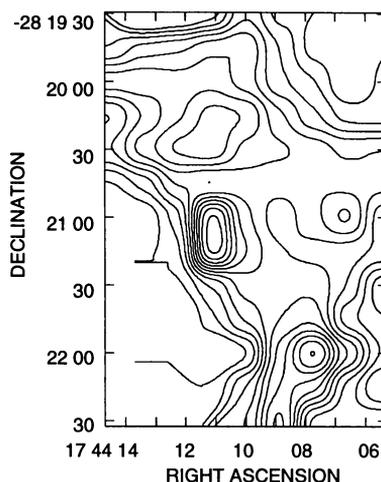


Figure 1. Integrated intensity map of $\text{CH}_3\text{CH}_2\text{OH } 7_{07} - 6_{16}$ toward Sgr B2. The lowest contour is 2 K km s^{-1} and the interval is 0.5 K km s^{-1} .

NH_3 transitions and found two hot condensations with diameters of 0.2 pc. The northern of these, $\text{NH}_3(\text{N})$, has an enormous NH_3 column density of 10^{20} cm^{-2} for a temperature of 200 K. They assumed an NH_3 abundance of 10^{-5} , and got the mass of the clump to be $5000 M_{\odot}$.

Several spectral scan projects toward the Sgr B2(M) and (N) regions exist. A molecular line survey of Sgr B2(M) and (N) was carried out by Sutton et al. (1991) with the JCMT and CSO in the frequency range 330 to 355 GHz. Two spectral scans toward three positions, Sgr B2(M), (N) and (NW), are almost finished: a survey by the 45m telescope of Nobeyama in the frequency range 30 to 116 GHz (Ohishi et al., 1996) and a survey by the SEST in the frequency range 222 and 255 GHz (Nummelin et al., 1996). Sgr B2(NW) ($\Delta\alpha = -60''$, $\Delta\delta = 45''$ from Sgr B2(M)) was a local peak of column density of HC_3N and contains no ultra-compact HII regions. Therefore the evolutionary sequence among three positions would be (NW) \rightarrow (N) \rightarrow (M), and comparisons of molecular compositions of three positions will tell us a relation of chemical evolution with physical evolution. Molecular species seen toward Sgr B2(NW) include linear carbon-chain molecules such as HC_7N . Saturated organic molecules such as CH_3OH , $\text{CH}_3\text{CH}_2\text{OH}$, HCOOCH_3 , $(\text{CH}_3)_2\text{O}$, $\text{CH}_3\text{CH}_2\text{CN}$ and molecules in vibrationally excited states show the strongest emissions toward Sgr B2(N). As described in the case of Orion KL, these molecules are difficult to form via gas phase reactions and thought to form on the grain mantles followed by evaporation. Their high ($> 70 \text{ K}$) excitation temperatures may support such an idea.

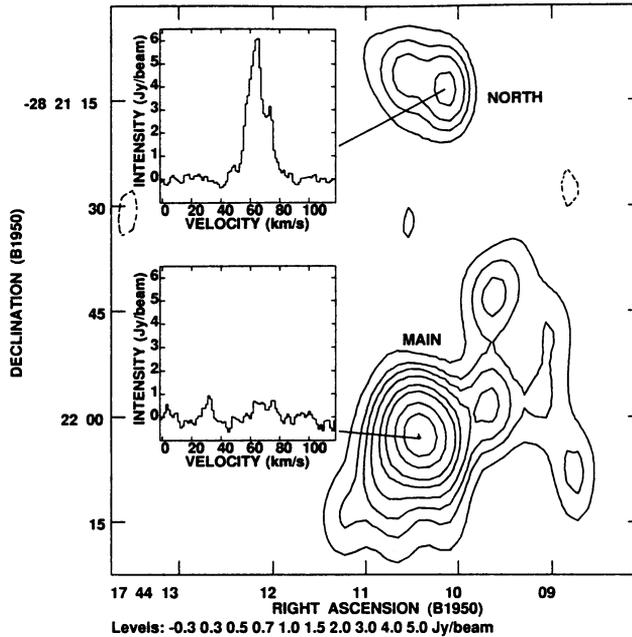


Figure 2. Contour continuum image of Sgr B2(M) and (N) at 3mm. EtCN $10_{1,10} - 9_{1,9}$ spectra are shown toward both continuum peaks, illustrating the chemical differences between the two sources (from Miao et al. 1995).

On the other hand, SO and SO₂ peak toward Sgr B2(M).

Ohishi et al. (1996) made mapping observations in transitions of CH₃OH, HCOOCH₃, (CH₃)₂O and CH₃CH₂OH and confirmed that distributions of these molecules peak toward Sgr B2(N). A sample map is shown in Figure 1. Recent BIMA observations (Miao et al. 1995, Kuan & Snyder 1996) have provided high resolution images around Sgr B2(N) and these saturated molecules strongly peak at the ultra-compact region, K1–K3 (see Figure 2). HNCO and NH₂CHO also peak at this position (Kuan & Snyder 1996).

4. Other Hot Core sources

Recent millimeter and submillimeter observations toward a large number of ultra-compact HII regions by Churchwell et al. (1990) and Cesaroni et al. (1992) have shown that several other regions have qualitatively similar characteristics with the Orion Hot Core, the Orion compact ridge and Sgr B2(N). Cesaroni et al. carried out observations in the NH₃ (4,4) and (5,5) lines. They found high excitation NH₃ emission in 15 out of 16 regions

surveyed and deduced temperatures of order 100 K. Cesaroni et al. (1994) used the VLA and suggested that high column densities of NH_3 ($N(\text{NH}_3) \sim 10^{18} - 10^{19} \text{ cm}^{-2}$) are an indicator of a hot core and that such regions have kinetic temperatures of 50 – 200 K. They also estimated typical linear sizes of hot cores of ~ 0.1 pc. In the following, we discuss observational results of several hot core regions.

4.1. G34.3+0.15

The ultra-compact HII region G34.3+0.15 first attracted attention due to the cometary nature of its radio continuum distribution (Reid & Ho, 1985). Henkel et al. (1987) detected 15 NH_3 transitions with energies up to 940 K and concluded that the molecular line emission came from a region of temperature 225 K. They estimated the size of the emitting region to be 0.4 pc on the basis of their single-dish observations, and indeed the NH_3 (3,3) map of Heaton et al. (1989) shows a cone of roughly this dimension, which appears to wrap around the head of the cometary HII region. The molecular core and ionized gas are embedded in a more extended region and contain several thousand solar masses of gas.

A spectral line survey between 330 and 360 GHz was carried out with the JCMT by Macdonald et al. (1996). There are similarities in that saturated nitrogen-containing molecules appear to be abundant. Millar et al. (1995) also found several $\text{CH}_3\text{CH}_2\text{OH}$ transitions in their data base and derived an excitation temperature of 125 K and a beam-averaged column density of $2 \times 10^{15} \text{ cm}^{-2}$, corresponding to a fractional abundance relative to H_2 of 4×10^{-9} . This large abundance cannot be made by pure gas-phase processes, and they conclude that the ethanol must be formed efficiently in the grain surface chemistry. Macdonald et al. (1995) have mapped this object in the $J=6-5$ CH_3CN line using the Nobeyama Millimeter Array and find a compact source coincident with the cores seen in NH_3 (3,3). They have also obtained an IRCAM K-band image with $0.6''$ resolution which shows emission at $2\mu\text{m}$ coincident with that seen in NH_3 (3,3).

4.2. W51E1/E2 AND W51D

The W51 cloud was mapped using the VLA in NH_3 (3,3) emission by Ho et al. (1983). This map made clear the existence of three warm molecular clumps close to, but not exactly coincident with, the compact HII regions associated with W51. Actually, the H_2O maser positions agreed rather better with the NH_3 clumps than the contours of the radio continuum.

Subsequent single-dish observations by Mauersberger et al. (1986, 1987) showed that the NH_3 column density was $2 \times 10^{19} \text{ cm}^{-2}$, a factor of four larger than that found by Genzel et al. (1982) toward Orion KL. They

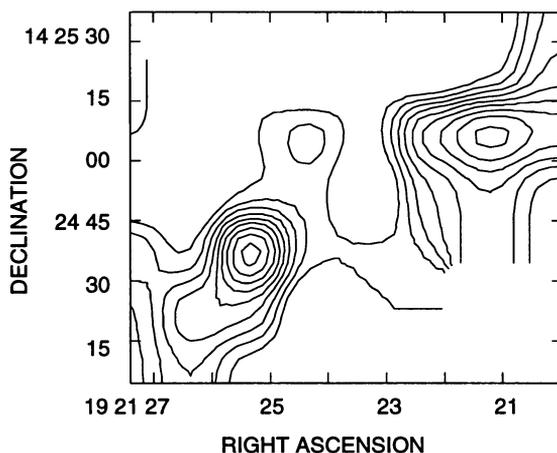


Figure 3. Integrated intensity map of $\text{CH}_3\text{CH}_2\text{OH } 7_{07} - 6_{16}$ toward W51e1/e2 (left) and W51d (right). The lowest contour is 0.1 K km s^{-1} and the interval is 0.1 K km s^{-1} .

also deduced a mass of $160 M_{\odot}$ for the NH_3 clump by assuming virial equilibrium and an NH_3 abundance of 6×10^{-6} , which is a few orders of magnitude larger than that in typical molecular clouds.

Ohishi et al. (1996) made mapping observations in transitions of CH_3OH , HCOOCH_3 , $(\text{CH}_3)_2\text{O}$ and $\text{CH}_3\text{CH}_2\text{OH}$ and found that these species are localized at W51e1/e2 and W51d using the 45m telescope of Nobeyama (Figure 3). These characteristics, as well as enhanced NH_3 abundance, are quite similar with the cases of Orion KL and Sgr B2(N).

5. Surveys of the Hot Core molecules

As we have seen, saturated molecules (H_2O , NH_3 , CH_3OH , $\text{CH}_3\text{CH}_2\text{OH}$, and so on) are known to be very abundant in Hot Core sources. Most of these molecules are difficult to form in pure gas-phase chemical reaction schemes. They are thought to be formed on grain surfaces and evaporate. This idea seems to work reasonably well, however, observational conclusions are still indirect. Therefore it is important to survey many Hot Core sources in the “Hot Core” molecules and to see whether these molecules are commonly observed in Hot Cores. Further, excitation temperatures, fractional abundances of these species and comparisons with dust temperatures may strengthen the evaporation story.

5.1. HDO

Water is thought to be the most abundant molecule next to H_2 and its abundance is almost equal to that of CO. It plays an important role in the interstellar chemistry and in the cooling of molecular clouds. In the high temperature limit, the ratio $[HDO]/[H_2O]$ must be equal to the cosmic $[D]/[H]$ ratio of $\sim 10^{-5}$. If HDO is fractionated, it means that HDO (and H_2O) was formed on cold (~ 10 K) grain surfaces.

Surveys of HDO were made by Henkel et al. (1987), Jacq et al. (1990) and Shultz et al. (1991) toward several star forming regions. They conclude that the abundance of HDO is enhanced by factors of 10 to 100 over the interstellar $[D]/[H]$ ratio. Gensheimer et al. (1996) made a sensitive survey of HDO and $H_2^{18}O$ with the IRAM 30m telescope, and succeeded to detect 9 sources of HDO and 16 sources of $H_2^{18}O$. Using these data they derived the ratio $[HDO]/[H_2O] \sim 3 \times 10^{-4}$. They also made maps of HDO and $H_2^{18}O$ toward Orion IRC2 and Sgr B2, finding that the $H_2^{18}O$ emission peaks toward Sgr B2(N). The inferred abundances, compact sizes and distributions of the emission regions lead them to conclude that evaporation of grain mantles in the hot cores must play an important role in the formation of interstellar gas phase water in these regions.

5.2. ALCOHOLS, $HCOOCH_3$ AND $(CH_3)_2O$

Ohishi et al. (1996) made a survey with CH_3OH , CH_3CH_2OH , $HCOOCH_3$ and $(CH_3)_2O$ and detected them in Sgr B2(N), Orion KL, W51e1/e2, W51d, NGC6334F, G34.3+0.15, NGC7538 and W3(OH). They could detect CH_3CH_2OH , $HCOOCH_3$ and $(CH_3)_2O$ for the first time in the latter four sources (except for CH_3CH_2OH in G34.3+0.15). The excitation temperatures of CH_3CH_2OH were typically 70 K in these sources and the fractional abundances were $10^{-8} - 10^{-10}$. They also derived the fractional abundances of $HCOOCH_3$ and $(CH_3)_2O$ to be $10^{-9} - 10^{-8}$ and $10^{-8} - 10^{-6}$, respectively. No pure gas-phase reaction models produce such high abundances, and chemical models that incorporate gas and dust give better results.

5.3. CH_2NH

CH_2NH (methylenimine) has been securely detected only in Sgr B2 (Godfrey et al., 1973). Its non-detection in other sources has long been a puzzle. Very recently Dickens et al. (1996) have succeeded to detect several transitions of CH_2NH convincingly in hot core sources (Figure 4). The excitation temperatures of CH_2NH are around 100 K in the hot core sources and the ratio $[CH_2NH]/[HCN]$ is an order of magnitude higher than the prediction by chemical models. Based on these results, Dickens et al. have suggested

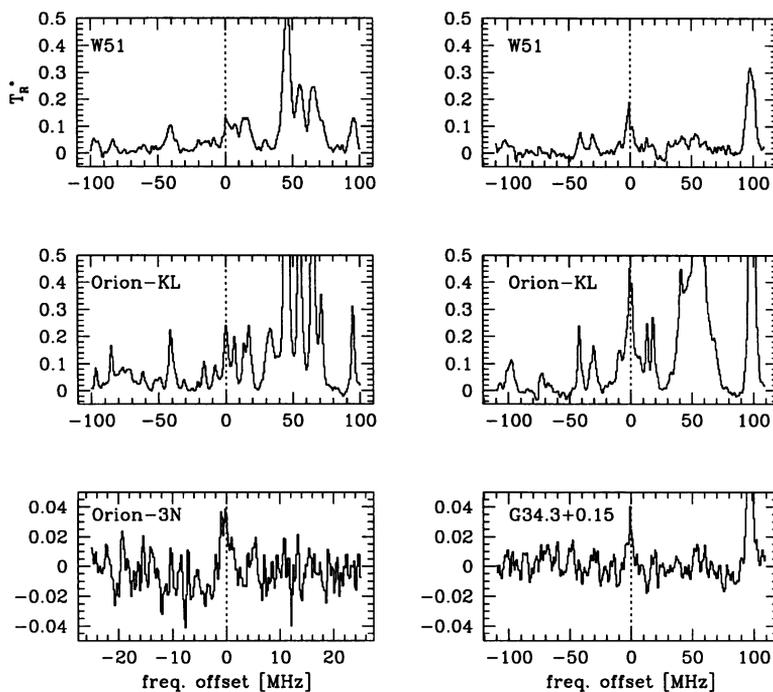


Figure 4. New detections of CH_2NH . Left panels are the $1_{1,1} - 0_{0,0}$ transition at 225554.69 MHz and the right ones are the $4_{1,4} - 3_{1,3}$ transition at 245125.98 MHz.

that additional production pathways for CH_2NH are necessary, probably formation on grain surface.

6. Prospects

Recent improvements of the sensitivities of radio telescopes have made it possible to detect many “Hot Core” molecules and have strengthened the theory that these molecules are formed on grain surfaces and evaporated from the surfaces. However, I believe we need to get more information on the Hot Core sources observationally, as follows.

As the high spatial resolution observations (eg., Cesaroni et al. 1994a,b; Miao et al. 1995; Kuan & Snyder 1996) show, detailed studies of interface regions between ionized and neutral material are quite important for the understanding of the physical and chemical processes in the hot core sources. As the number of samples increases we will be able to develop a more general picture of the hot cores.

It is necessary to know which molecules are formed on the grain surfaces and have enhanced abundances in the hot core regions. The candidates

may be saturated molecules which are detected only in Sgr B2 ; CH_3NH_2 , NH_2CHO , NH_2CN (see Table 1). Important parameters are the fractional abundances of the molecules to make comparisons between observations and models. However, it is sometimes difficult to estimate fractional abundances due to uncertainties in the column densities of H_2 . Therefore dust continuum observations toward Hot Cores are quite important. Surveys of the "Hot Core" molecules are also needed to study the relationship between observed excitation temperatures and kinetic/dust temperatures. Comparison of these temperatures with the sublimation temperature of a specific molecule will provide evidence for evaporation of the molecule.

Because Hot Cores are "hot" and excitation temperatures of molecules are so high, short-millimeter and submillimeter observations have the advantage that, in general, observed intensities are much higher than those in centimeter and long-millimeter observations. There are several projects to construct large millimeter and submillimeter interferometers: SMA, MMA, LMSA and LSA. When these instruments are available, our understandings on the Hot Cores will be improved dramatically.

References

- Blake, G.A., Sutton, E.C., Masson, C.R., Phillips, T.G. 1987, *Astrophys.J.*, 315, 621
 Brown, P.D., Charnley, S.B., Millar, T.J. 1988, *Mon. Not. R. Astron. Soc.*, 231, 409
 Caselli, P., Hasegawa, T.I., Herbst, E. 1993, *Astrophys.J.*, 408, 548
 Cesaroni, R., Walmsley, C.M., Churchwell, E. 1992, *Astron. Astrophys.*, 256, 618
 Cesaroni, R., Olmi, L., Walmsley, C.M., Churchwell, E., Hofner, P. 1994a, *Astrophys.J.*, 435, L137
 Cesaroni, R., Churchwell, E., Hofner, P., Walmsley, C.M., Kurtz, S. 1994b, *Astron. Astrophys.*, 288, 903
 Churchwell, E., Walmsley, C.M., Cesaroni, R. 1990, *Astron. Astrophys. Suppl.*, 83, 119
 Dickens, J.E., Irvine, W.M., DeVries, C.H., Ohishi, M. 1996, *Astrophys.J.*, submitted
 Gensheimer, P.D., Mauersberger, R., Wilson, T.L. 1996, *Astron. Astrophys.*, 314, 281
 Genzel, R., Downes, D., Ho, P.T.P., Bieging, J.H. 1982, *Astrophys.J.*, 259, L103
 Genzel, R., Stutzki, J. 1989, *Ann. Rev. Astron. Astrophys.*, 27, 41
 Gerin, M., Combes, F., Włodarczak, G., Encrenaz, P., Laurent, C. 1992, *Astron. Astrophys.*, 253, L29
 Godfrey, P.D., Brown, R.D., Robinson, B.J., Sinclair, M.W. 1973, *Astrophys. Lett.*, 13, 119
 Goldsmith, P.F., Snell, R.L., Hasegawa, T., Ukita, N. 1987, *Astrophys.J.*, 314, 525
 Heaton, B.D., Little, L.T., Bishop, I.S. 1989, *Astron. Astrophys.*, 213, 148
 Henkel, C., Wilson, T.L., Mauersberger, R. 1987, *Astron. Astrophys.*, 182, 137
 Henkel, C., Mauersberger, R., Wilson, T.L., Snyder, L.E., Menten, K.M., Wouterloot, J.G.A. 1987, *Astron. Astrophys.*, 182, 299
 Hermsen, W., Wilson, T.L., Bieging, J.H. 1988, *Astrophys.J.*, 201, 276
 Ho, P.T.P., Genzel, R., Das, A. 1983, *Astrophys.J.*, 266, 596
 Irvine, W.M., Goldsmith, P.F., Hjalmarson, Å. 1987, *Interstellar Processes*, eds. D.J. Hollenbach and H.A. Thronson Jr. (Reidel, Dordrecht) p.561
 Jacq, T., Walmsley, C.M., Henkel, C., Baudry, A., Mauersberger, R., Jewell, P.R., 1990, *Astron. Astrophys.*, 228, 447
 Kuan, Y.J., Snyder, L.E. 1996, *Astrophys.J.*, 470, 981

- Macdonald, G.H., Habing, R.J., Millar, T.J. 1995, *Astrophys. and Space Science*, 224, 177
- Macdonald, G.H., Habing, R.J., Millar, T.J. 1996, *Astron. Astrophys. Suppl.*, in press
- Martin, A.H.M., Downes, D. 1972, *Astrophys. Lett.*, 11, 219
- Martín-Pintado, J., de Vicente, P., Wilson, W.L., Johnston, K.J. 1990, *Astron. Astrophys.*, 236, 193
- Mauersberger, R., Henkel, C., Jacq, T., Walmsley, C.M. 1988, *Astron. Astrophys.*, 194, L1
- Mauersberger, R., Henkel, C., Wilson, T.L. 1987, *Astron. Astrophys.*, 173, 352
- Mauersberger, R., Henkel, C., Wilson, T.L., Walmsley, C.M. 1986, *Astron. Astrophys.*, 162, 199
- Miao, Y., Mehringer, D.M., Kuan, Y.J., Snyder, L.E. 1995, *Astrophys.J.*, 445, L59
- Migenes, V., Johnston, K.J., Pauls, T.A., Wilson, T.L. 1989, *Astrophys.J.*, 347, 294
- Millar, T.J., Herbst, E., Charnley, S.B. 1991, *Astrophys.J.*, 369, 147
- Millar, T.J. 1993, in *Dust and Chemistry in Astronomy*, eds. T.J. Millar and D.A. Williams (Institute of Physics Publishing, Bristol), p.249
- Millar, T.J., Macdonald, G.H., Habing, R.J. 1995, *Mon. Not. R. Astron. Soc.*, 273, 25
- Minh, Y.C., Ohishi, M., Roh, D.G., Ishiguro, M., Irvine, W.M. 1993, *Astrophys.J.*, 411, 773
- Morris, M., Palmer, P., Zuckerman, B. 1980, *Astrophys.J.*, 237, 1
- Nummelin, A., Hjalmarson, Å., Bergman, P., Irvine, W.M., Ohishi, M. 1996, in preparation
- Ohishi, M., Ishikawa, S., Yamamoto, S., Saito, S., Amano, T. 1995, *Astrophys.J.*, 446, L43
- Ohishi, M., Ishikawa, S., Ikeda, M. 1996, in preparation
- Ohishi, M., Ishikawa, S., Saito, S. 1996, in preparation
- Pauls, T.A., Wilson, T.L., Bieging, J.H., Martin, R.N. 1983, *Astron. Astrophys.*, 124, 23
- Plambeck, R.L., Wright, M.C.H., Welch, W.J. Bieging, J.H., Baud, B., Ho, P.T.P., Vogel, S.N. 1982, *Astrophys.J.*, 259, 617
- Plambeck, R.L., Wright, M.C.H. 1987, *Astrophys.J.*, 317, L101
- Reid, M.J., Ho, P.T.P. 1985, *Astrophys.J.*, 288, L17
- Saito, S., Mikami, H., Yamamoto, S., Murata, Y., Kawabe, R. 1994, in *Astronomy with Millimeter and Submillimeter Wave Interferometry*, eds. M. Ishiguro and W.J. Welch, ASP Conference Series, Vol. 59, p.241
- Shultz, A., Güsten, R., Serabyn, E., Walmsley, C.M. 1991, *Astron. Astrophys.*, 246, L55
- Sutton, E.C., Jaminet, P.A., Danchi, W.C., Blake, G.A. 1991, *Astrophys.J.Suppl.*, 311, 921
- Turner, B.E. 1990, *Astrophys.J.*, 362, L29
- Vogel, S.N., Genzel, R., Palmer, P. 1987, *Astrophys.J.*, 316, 243
- Walmsley, C.M., Hermsen, W., Henkel, C., Mauersberger, R., Wilson, T.L. 1987, *Astron. Astrophys.*, 172, 311
- Walmsley, C.M., Schilke, P. 1993, in *Dust and Chemistry in Astronomy*, eds. T.J. Millar and D.A. Williams (Institute of Physics Publishing, Bristol), p.37
- Werner, M.W., Dinerstein, H.L., Capps, R.W. 1983, *Astrophys.J.*, 265, L13
- Wilson, T.L., Walmsley, C.M. 1989, *Astron. Astrophys. Review*, 1, 141
- Wright, M.C.H., Plambeck, R.L., Mundy, L.G., Looney, L.W. 1995, *Astrophys.J.*, 455, L185

Discussion

Wilson: Could you elaborate on the apparent presence of ethyl alcohol in the region 40" north of SgrB2(N)? This seems to be a very young source without much internal heating. Thus the formation of gas phase $\text{CH}_3\text{CH}_2\text{OH}$ might not arise from evaporation from grains. Could you comment on this?

Ohishi: The $\text{C}_2\text{H}_5\text{OH}$ peak at 40" north of SgrB2(N) is real. In this region, HNC and HOCO^+ , indicators of FIR radiation, peak. Furthermore, quite strong CH_3OH maser emission at 36 GHz ($4_{-1} - 3_0$ E) peaks here. These facts strongly suggest that very young stars are forming in this region, leading to evaporation of CH_3OH and $\text{C}_2\text{H}_5\text{OH}$ off grain mantles.

Van Dishoeck: High-abundances of deuterated molecules seem to be a characteristic of hot core regions, at least in Orion/KL. Can you comment on the observational situation for other hot cores?

Ohishi: We tried to survey HDO at 80 GHz in several hot core sources, such as SgrB2. We found $\text{HDO}/\text{H}_2\text{O} \approx 10^{-5} - 10^{-4}$. If we consider that these values have large uncertainties, HDO is not so much enhanced, contrary to the case in Orion/KL.

Mauersberger: Where did you get the water abundance from?

Ohishi: We assumed the abundance of water to be 10^{-5} , from chemical model calculations.

Wootten: Comment: While the spectrum of NH_2D in SgrB2 attests to its abundance there, it may not be clear that this abundance requires hot core chemistry. I have surveyed $\text{NH}_2\text{D}/\text{NH}_3$ in a large number of clouds, finding that this ratio mimics the $\text{DCO}^+/\text{HCO}^+$ ratio. This requires NH_2D to arise from reactions with H_2D^+ in most regions. In hot cores, $\text{NH}_2\text{D}/\text{NH}_3$ does not mimic $\text{DCO}^+/\text{HCO}^+$ suggesting a second source of NH_2D , most plausibly grain surface evaporation, as you suggest.