EXTENSIVE MOLECULAR LINE SURVEY FOR DARK CLOUDS

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1. Nobeyama Spectral Line Survey

Since 1984 the molecular line search for dark clouds, mainly TMC1, for wide frequency ranges in the short cm- and mm-waverength regions has been proceeded at Nobeyama Radio Observatory using the 45-m telescope. The main collaborators are: H.Suzuki, M.Ohishi, S.Saito, Y.Yamamoto, K.Kawaguchi, and N.Kaifu.

The unbiased and wide frequency coverage molecular line survey for dark clouds is by no means basically important from the standpoint of view of the interstellar chemistry and chemical evolution of dark clouds. However such extensive line survey has not been performed yet, because of some practical difficulties. Very narrow linewidth observed in dark clouds (about 0.5 km s^{-1}) requires high frequency resolution, while the wide frequency region should be covered. The line intensity is relatively weak due to the low kinetic temperature of dark clouds. The narrow lines are very often difficult to distinguish from the confusion of weak spurious signals which are mixed from the local oscillators etc. Thus such survey is enevitably a very time consuming effort.

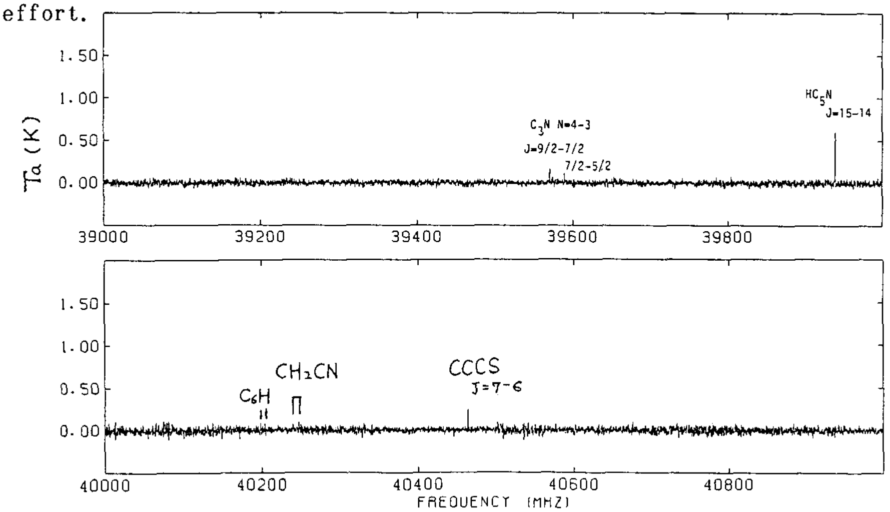

Figure 1. A sample of the 2GHz spectrum(39-41 GHz) of TMC1 taken with the 45m telescope and the wideband AOS(250KHz resolution and 16000 channel).

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We have started the spectral line survey for TMC1 and some other sources by using the Nobeyama 45m telescope, wideband receivers and AOS spectrometers.

The AOS, acousto-optical radiospectrometer, has been first developed extensively at the Tokyo Astronomical Observatory (Kaifu et al. 1977) and then at Nobeyama (kaifu and Chikada 1984). The Nobeyama AOS consists of two systems, one is the wideband AOS with 16000 channel outputs, 250KHz resolution and 8 x 250MHz bandwidth. The other is the high-resolution system which provides 16000 channel, the resolution of 37KHz and the bandwidth of 8 x 40MHz. This large spectrometer system can be used simultaneously by connecting to one or two cooled receivers some of which also provide 2GHz simultaneous bandwidth. These large spectroscopic systems were essential for our survey, still the survey is by no means easy.

So far the survey has been performed in the frequency regions of 8.8-10.8GHz, 14-16GHz, 18-21GHz, 22-24GHz, 36-50GHz, and several fragmentary frequency bands in 88-110GHz. The frontend receivers used were the cooled HEMT amps for the 8-24GHz band, the cooled Schottky mixers and then a Nb SIS mixer later for the 36-50GHz band, and a cooled Schottky mixer for the 88-110GHz region. The obtained rms noise temperature of the data vary from 3mK to 30mK, depending on the receiver and observational conditions. A sample data is shown in figure 1.

The detailed results and discussion will be published elsewhere, and here we present the summary of the observed lines in table 1, and discuss some topics. As a whole we have detected 91 spectral lines of 27 molecules (including two marginal detections) and 16 lines of 14 isotopic species in TMC1. Some 25 lines are not yet identified to any known molecules.

molecule	number of lines		molecule	number of lines	
	main species	isotopic species		main species	isotopic species
CO	1	2	CH_3CN	1?	
NH_3	1		C_2H_3CN	2	
C_3N	4		$HNCO$	1	
CS	2	2	CH_3OH	1	
CCS *	4	1	CH_2CN *	11	
$CCCS$ *	3		H_2CS	2	
C_4H	10		H_2CCO	2	
C_6H *	12		CH_3COH	1?	
HCN	1	1	HCO^+	1	
HC_3N	6	4	HCS^+	1	
HC_5N	9	6	$HCCCOH$	1	
HC_7N	6		C_3H_2	2	
HC_9N	2		$c-C_3H$ *	4	
$CCCO$	1		Unidentified	25	——

Table 1. Observed molecular lines in the NRO spectral survey for TMC1
* : Molecule newly detected or identified during this survey.

During this survey we have detected several new interstellar molecules. These are: C_6H (Suzuki et al.,1986), CCS (Suzuki et al.,1984, Kaifu et al.,1987, Saito et al., 1987), CCCS (Yamamoto et al., 1987a, Kaifu et al., 1987), cyclic C_3H (Yamamoto et al., 1987b), CH_2CN (Irvine et al., 1988, Saito et al., 1989), HCCCOH (Irvine et al., 1989). Especially the detection of CCS and CCCS added a new series of carbon chain molecules containing S, which is pretty abundant in TMC1 (see figure 2). The CCS was first detected as a strong unidentified line and 4 years later it was identified with a new molecule CCS by chance. The column density of CCS in TMC1 is $9 \times 10^{13} cm^{-2}$ and can be compared with those of CS($2 \times 10^{14} cm^{-2}$) and of HCN($1.2 \times 10^{14} cm^{-2}$).

2. Carbon Chain Molecules and CCS

The detections of CCS and CCCS provided a new aspect to the formation of carbon chain molecules, which characterize the dark cloud chemistry as can be seen in table 1. In spite of relatively low cosmic abundance of S it seems that the sulphur-containing carbon chain molecules are pretty abundant. Also the series of C_nH and C_nS chains show the continuous number of carbon atoms, though the relative abundances vary with n (see figure 3). On the other hand the previously known carbon chains HC_nN are found for only odd n.

Suzuki (1987) proposed an idea to explain such observational tendencies of carbon chain molecules. The carbon chain molecules may grow first as pure carbon chains which are "bones" of observed carbon chain molecules in the partially ionized C^+ regions of dark clouds (Suzuki 1983). Then the bones are combined with H, N, O, S etc. to form stable molecules like HC_nN. C_nS could be formed simultaneously to or just after the formation of carbon bones, because the low ionization potential of S allow it to form the relatively deep S^+ region at the cloud surface, and here the sulphur chemistry should be active.

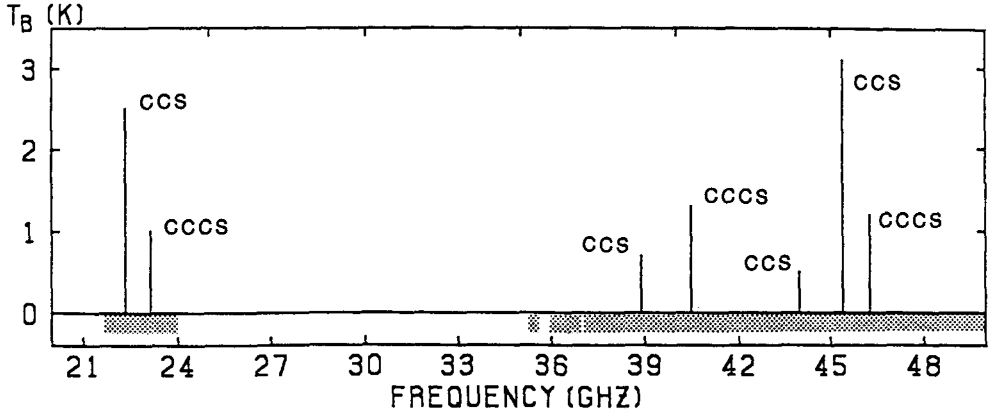

Figure 2. A schematic diagram of CCS and CCCS spectrum detected in the survey. The hatched area show the surveyed frequency range.
(taken from Kaifu et al., 1987)

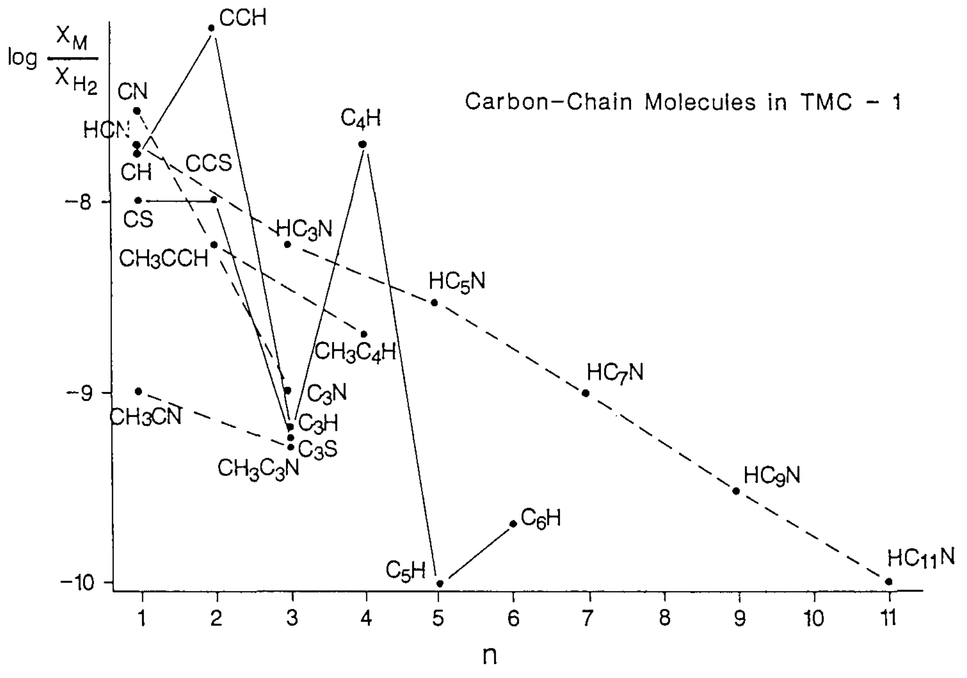

Figure 3. Abundances of carbon chain molecules in TMC1, as a function of number of carbon chain atoms n. Dashed line indicates the "odd n only" and "even n only" chain molecules. Values were taken from Irvine et al. 1987, Suzuki et al. 1986, Saito et al. 1987, Yamamoto et al. 1987a.

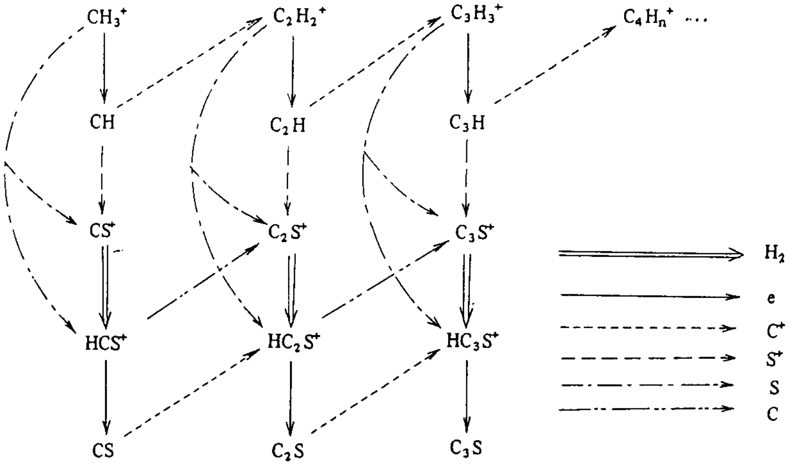

Figure 4. A schematic flow of possible C_nS formation process in the partially ionized region, taken from Suzuki (1987).

A schematic diagram of C_nS formation in the S^+ region is given by Suzuki (figure 4). The C_nS chains are not very stable and will be changed to be more stable species in denser region. Therefore the C_nS might be a good probe of the cloud evolution to trace the chemistry in the various stages of contraction of dark clouds.

We are making extensive observations to test the distribution of CCS in various dark clouds and inside some selected clouds and to compare them to those of other molecules like CS, NH_3, HC_3N etc(Yamamoto et al., 1989, Hirahara et al., 1989). Figure 5 shows a comparison of distributions of CCS and CS in TMC1, showing remarkable difference between the distributions of these two molecules. Another remarkable fact about CCS is that it cannot be found in the star forming regions where the density is high and accompanied with various shocks and heating effects. Such observational facts would be interpreted in terms of the combination of the chemical and physical evolution of the dark clouds.

Furthermore the recent detection of CH_2CN (Irvine et al.,1988, Saito et al., 1989) dramatically showed that abundant (NL of 10^{13}-$10^{14}cm^{-2}$) complex organic molecules might be detected as very weak signals because of their complex energy level structures. Such spectral lines would distribute in relatively longer wavelength regions. In NRO we plan to extend our survey to complete the frequency range from 8GHz to 50 GHz with higher sensitivity, by using wideband cooled HEMT amplifiers and SIS receivers. Also the spectral scans for 70-120GHz by using new SIS receivers will start in next winter.

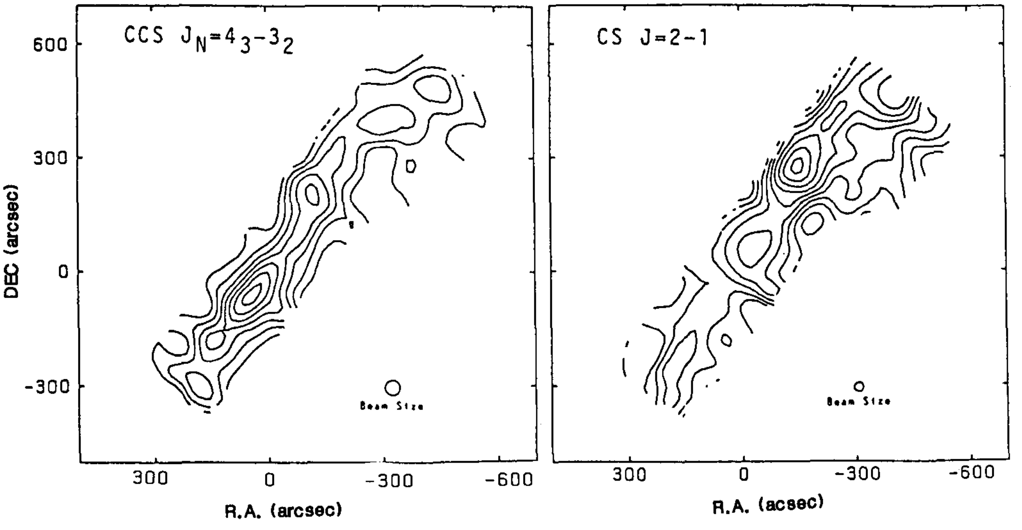

Figure 5. A map of CCS distribution in TMC1 (left) compared with an NH_3 map (right), taken with the 45m telescope (Hirahara et al., 1989).

The author offer his condolences to the late Dr. Hiroko Suzuki (1947-1987), who was a very distinguished astrophysicist, the most active staff member of Nobeyama Radio Observatory and was our best colleague and friend.
She was one of the pioneers of astrochemistry, she was at the center of the Nobeyama molecular line survey. She died on 22 November, 1987, the result of a car accident. Her great contributions to astrochemistry and to radio astronomy, and her very active life will remain in our memory forever.

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