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Author(s)	Sakurai, T.; Dobashi, K.; Kaiden, M.; Nishiura, S.; Takano, S.; Kawara, K.; Oyabu, S.; Kozasa, T.; Fukuhara, K.
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MOLECULAR CLOUD CORE MCLD 123.5+24.9 IN POLARIS CIRRUS.

T. Sakurai[1], K. Dobashi[1], M. Kaiden[1], S. Nishiura[1], S. Takano[2], K. Kawara[3], S. Oyabu[3], T. Kozasa[4], and K. Fukuhara[4], [1]Tokyo Gakugei University, Koganei, Tokyo 184-8501 (T. Sakurai: m041833s@u-gakugei.ac.jp), [2]Nobeyama Radio Observatory, Minamisaku-gun, Nagano 384-1305, [3]University of Tokyo, Mitaka, Tokyo 181-0015, [4]University of Hokkaidou, Sapporo, Hokkaidou 060-0810

Introduction: Polaris cirrus is a diffuse cloud in the direction of the north celestial pole. Overall distribution of the extensive cirrus cloud was first revealed by Heithausen and Thaddeus through CO observations using the CfA 1.2m telescope [1]. Even in such a diffuse cirrus cloud, dense cores probably leading to star formation are sometimes discovered by the observations using high-density tracers, e.g., NH_3 and CS [2]. MCLD 123.5+24.9 is one of such unusual cores. Based on CS observations, Heithausen found that there are three dense condensations inside MCLD 123.5+24.9 [3]. Among these condensations referred to as “A” to “C” in this article, Heithausen detected a double peaked CS profile toward “C”, the southmost condensation among the three. Because the shape of the CS line is typical of infalling dense cores [4], he suggested that the condensation “C” has started to collapse, possibly forming a very low mass star close to the brown dwarf mass-limit. It is of great interest that a star can form in a diffuse cloud such as the Polaris cirrus.

Purpose of the present study is to observe MCLD 123.5+24.9 in various wavelengths from the optical (BVRI bands) to the radio (a score of molecular emission lines), which should provide us basic materials to investigate the nature and origin of the peculiar dense core.

Table 1: Observed Molecular Lines

Molecule	Transition	Frequency (GHz)	Beam Size (arcsec)	ΔT_{rms} (K)
HC_5N	J=17-16	45.264721	36.9	0.11
CCS	J_N=4_3-3_2	45.379033	36.8	0.12
HC_3N	J=5-4	45.490316	36.7	0.12
$C^{34}S$	J=1-0	48.206956	34.6	0.14
H_2CO	J_{KaKc}=4_{13}-4_{14}	48.284521	34.6	0.17
CH_3OH	J_{KaKc}=1_{01}-0_{00} A^+	48.372467	34.5	0.17
CS	J=1-0	48.990964	34.1	-----
HCO^+	J=1-0	89.188518	18.7	0.28
N_2H^+	J=1-0	93.173809	17.9	0.32
$C^{34}S$	J=2-1	96.412982	17.3	0.14
CH_3OH	J=2-1	96.741420	17.2	0.12
CS	J=2-1	97.980968	17.0	0.27
SO	J_N=2_3-1_2	99.299883	16.8	0.28
$C^{18}O$	J=1-0	109.782182	15.2	0.45
HNCO	J_{KaKc}=5_{05}-4_{04}	109.905753	15.2	0.53
^{13}CO	J=1-0	110.201353	15.1	0.25
^{12}CO	J=1-0	115.271204	14.5	-----

Observations: Radio observations were made for 8 days in 2003 December and in 2004 April using the 45m telescope at Nobeyama Radio Observatory (NRO). We employed three SIS mixer-receivers to perform simultaneous observations at ~45 and ~100 GHz. Spectrometers were AOS providing a frequency coverage and resolution of 40MHz and 40kHz, respectively. We summarize the observed molecular lines in Table 1.

Optical observations were made for 3 nights in 2003 December, 2004 January, and 2005 January using the 1.05m Schmidt telescope equipped with a 2kCCD camera at Kiso Observatory. We obtained deep images using the B, V, R, and I bandpass filters.

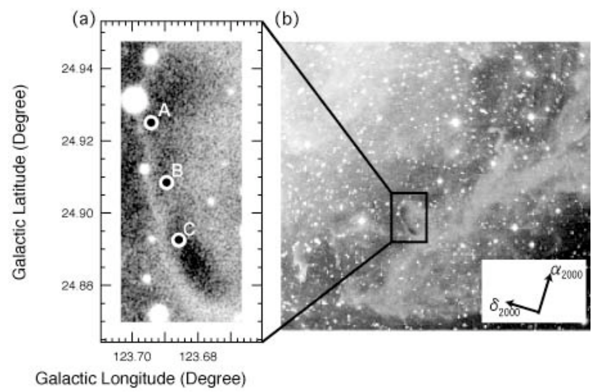

Figure 1: R band image of (a) the dense core MCLD 123.5+24.9 in the Polaris cirrus, and (b) its surroundings. Circles in panel (a) denote the positions of the three condensations reported by Heithausen (1999).

Results: Among the optical images we obtained, we show an R band image of MCLD 123.5+24.9 and its surroundings in Fig.1. The core appears as an extinction region enclosed by the scattered light. Figure 2 displays the integrated intensity maps of the $C^{34}S$ (J=1-0), $C^{34}S$ (J=2-1), CS (J=2-1), CCS (J_N=4_3-3_2), HC_3N (J=5-4), ^{13}CO (J=1-0), $C^{18}O$ (J=1-0), HCO^+ (J=1-0), and SO (J_N=2_3-1_2) emission lines shown on the same scale as in Fig.1a.

Positions of the three condensations reported by Heithausen [3] are indicated in Fig.1a and Fig.2c. For all of the emission lines detected in our observations, we calculated column densities of the molecules at the three positions, assuming the local thermodynamic equilibrium (LTE). Results are summarized in Table 2. In the calculation, we assumed a constant excitation temperature of 10K for all of the molecules and positions, which results in a slight inconsistency in the column densities of a certain molecule derived from different transitions, e.g., J=2-1 and 1-0 for $C^{34}S$.

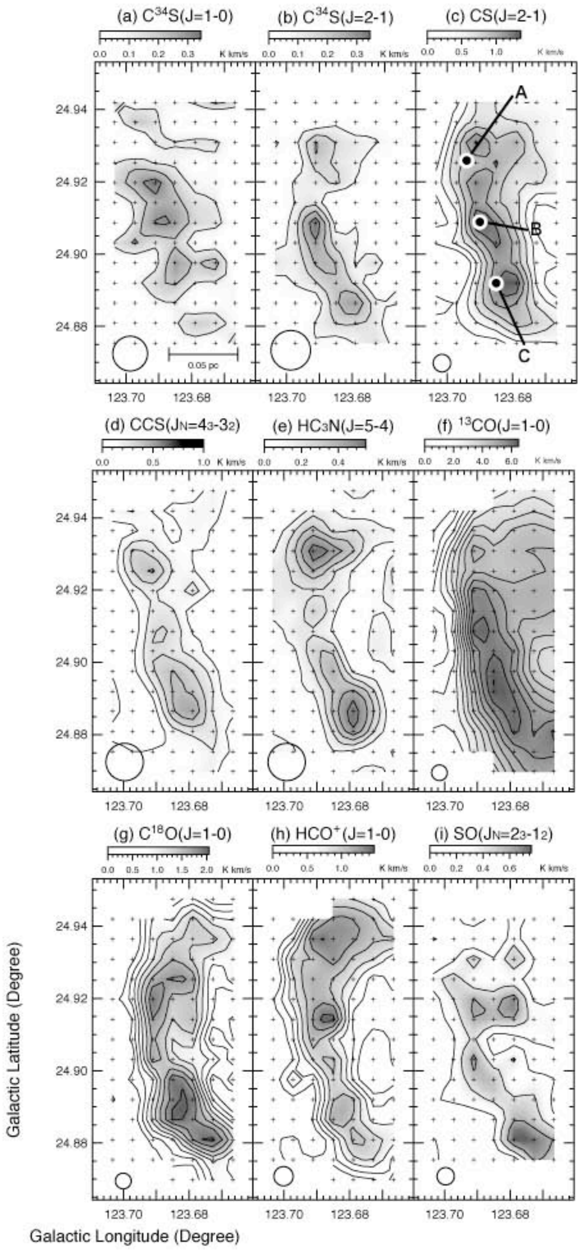

Figure 2: Integrated intensity maps of the observed molecular lines. The lowest contours and the contour intervals are 0.1 K km s^{-1} for panels (a), (b), (d), and (e), 0.2 K km s^{-1} for panels (c), (h), and (i), 0.25 K km s^{-1} for panel (g), and 0.5 K km s^{-1} for panel (f). Plus signs (+) indicate the observed positions (20" grid). The beam size is shown in the bottom-left corner of each panel by open circle. Three condensations found by Heithausen (1999) are denoted in panel (c).

Table 2: Derived Column Densities

Molecule	Transition	Column density		
		position A [cm^{-2}]	position B [cm^{-2}]	position C [cm^{-2}]
CCS	J_N=4_3-3_2	5.85×10^{12}	6.08×10^{12}	8.22×10^{12}
HC_3N	J=5-4	2.34×10^{12}	2.57×10^{12}	3.12×10^{12}
$C^{34}S$	J=1-0	4.89×10^{12}	3.06×10^{12}	4.43×10^{12}
CS	J=1-0	1.01×10^{13}	6.36×10^{12}	3.31×10^{12}
HCO^+	J=1-0	1.30×10^{12}	1.32×10^{12}	1.23×10^{12}
$C^{34}S$	J=2-1	....	1.85×10^{12}	1.86×10^{12}
CS	J=2-1	5.28×10^{12}	6.47×10^{12}	5.26×10^{12}
SO	J_N=2_3-1_2	3.40×10^{12}	8.62×10^{12}	....
$C^{18}O$	J=1-0	1.39×10^{15}	1.59×10^{15}	2.79×10^{15}
^{13}CO	J=1-0	9.01×10^{15}	1.19×10^{16}	1.32×10^{16}

Discussion and Summary:

Overall molecular distributions. The region where the various molecular emission lines are detected traces well the dust distribution seen as the optical extinction in Fig.1. However, the distributions of the individual molecular species are greatly different from each other, indicating a large variation of their fractional abundances in MCLD 123.5+24.9. There is a clear tendency that the emission lines of CS, CCS, and HC_3N that are expected to be more abundant in an early stage of chemical evolution are strongly detected over the core, while those of CH_3OH and N_2H^+ expected to form in a late stage are very weak or remain undetected. This indicates that MCLD 123.5+24.9 is a young dense core recently formed in the Polaris cirrus. As seen in Fig.2, CCS is more abundant in the southern part of the core. On the other hand, HCO^+ representing a late evolutionary stage is apparently more abundant in the northern part, suggesting that the northern part of the core is relatively more evolved than the southern region in terms of the chemical reactions.

Three condensations. Existence of the three condensations reported by Heithausen [3] can be easily confirmed in our dataset. It is noteworthy that there are interesting correlations and anti-correlations in the distributions of CCS, HC_3N, CS, and $C^{34}S$. Distributions of CCS and HC_3N are similar to each other, and their abundances are enhanced around the condensations “A” and “C”. On the contrary, CS and its isotope $C^{34}S$ are the most abundant around “B”. This may suggest that “B” is still young in comparison with the other condensations where a great portion of CS has already been converted into CCS. In fact, there detected many molecular lines toward “A” and “C”, including those of more evolved molecular species such as SO and CH_3OH.

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