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| その他のタイトル | 巨大分子雲における分子雲コアの化学的物理的性質 |
| 学位授与年月日 | 2017-03-23 |
| URL | http://doi.org/10.15083/00075599 |

論文の内容の要旨

# The chemical and dynamical nature of dense cores in giant molecular clouds

（巨大分子雲における分子雲コアの化学的物理的性質）

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Stars form in dense cores. Initial conditions of dense cores are the most important factors to determine formation process, masses and multiplicity of stars, and the nature of protoplanetary disks around them. Initial conditions of dense cores can be investigated in dense cores where star formation had has not started yet. Such dense core without star formation are often called "starless" dense cores. It is important to understand the nature of starless dense cores, in particular those on the verge of star formation because such starless dense cores must have the final condition just before star formation. However, it has been difficult to identify such dense cores partly because of short lifetime of starless dense cores on the verge of star formation and because of a lack of evolutional indicators of starless dense cores.

In dark clouds, chemical compositions of cores have been used as an indicator of evolutionary stages of cores ("chemical clock"). It is not clear, however, if chemical clocks established in cold cores also apply to warm cores whose temperature exceeds sublimation temperature of important players of chemical reaction networks such as CO, whose sublimation temperature is 25 K. Therefore, we evaluated several molecules like carbon-chain molecules (CCS, $HC_3N$), N-bearing molecules ($N_2H^+$, $NH_3$), and cyclic $C_3H_2$ as candidate tracers of chemical evolutions of the dense cores in two typical GMCs, the Orion A cloud and the Vela C giant molecular cloud complex, whose masses exceeding $10^4$ $M_\odot$ and temperature exceeding 30 K.

Using the Nobeyama 45-m telescope and KVN 21-m telescope, we derived the molecular abundances of CCS, cyclic $C_3H_2$, and $N_2H^+$ toward dense cores in the Orion A cloud. To detect weak emission lines, these observations were performed with high sensitivities. As a result, CCS emission from J=7-6 transition was detected for the first time towards the Orion A cloud. We found that the column density ratios of $N(N_2H^+)/N(CCS)$ and $N(c\text{-}C_3H_2)/N(CCS)$ are high in star forming cores while they are low in starless cores. We suggested that cyclic $C_3H_2$ is better tracer for warm evolved cores than $N_2H^+$. Furthermore, we used CCS, $HC_3N$ and $NH_3$ single-pointing observations data by Tatematsu et al. (2010) and Wilson et al. (1999). By these observations with high sensitivities, CCS emission from J=4-3 transition was detected for the first time towards the Orion A cloud. We found that $N(NH_3)/N(CCS)$ and $N(NH_3)/N(HC_3N)$ are high in star forming cores while they are low in starless cores. These results that the carbon chain molecules trace the chemically young cores, while N-bearing molecules trace the chemically evolved cores, are the same with earlier findings in dark clouds. In the case of $N(NH_3)/N(CCS)$ and $N(NH_3)/N(HC_3N)$, we confirmed that these tendencies are applied for a wide range of kinetic temperature, $T_{kin}$=10-60 K.

Subsequently, we confirmed these findings also apply to other GMC cores through observations of the $HC_3N$ and $N_2H^+$ molecules toward the Vela C molecular clouds with the Mopra 22-m telescope. Even though the spatial resolution of 53" corresponding to 0.19 pc cannot resolve individual dense cores, we found a tendency that the $N(N_2H^+)/N(HC_3N)$ is high in star forming region, while it is low in starless region. This is the similar tendencies in $N(N_2H^+)/N(CCS)$, $N(c\text{-}C_3H_2)/N(CCS)$, $N(NH_3)/N(CCS)$, and $N(NH_3)/N(HC_3N)$ found in the Orion A cloud.

By comparing the published data of $N(NH_3)/N(CCS)$ and $N(N_2H^+)/N(HC_3N)$ in dark clouds and infrared dark cloud clumps, we found the criteria between star forming and starless cores are $N(NH_3)/N(CCS)$ ~ 30-40 and $N(N_2H^+)/N(HC_3N)$ ~ 1-2. Using the chemical reaction network of UMIST Database for Astrochemistry (UDfA) assuming a density of $10^4$ cm$^{-3}$ and a temperature of 10 K, we estimated a timescale of $4\times10^5$-$1\times10^6$ yr forthese column density ratios achieve the criteria. This lifetime is several times longer than free-fall timescale and comparable to dissipation timescale of turbulence. Furthermore, we found a correlation between the chemical evolution and dissipation of turbulence ($R/R_{cr}$), suggesting that the chemical evolution can be an indicator of the dynamical evolution of the core and the timescale is determined by the dissipation of turbulence.

Finally, we selected one of the most chemically evolved starless cores in the Orion A cloud (TUKH122 core) by means of the $N(N_2H^+)/N(CCS)$ ratio and observed it in the $NH_3$ (J,K=1,1) and (J,K=2,2) lines with high sensitivity (rms ~ 40 mK) and spectral resolution (~ 0.05 km s$^{-1}$) by using the Nobeyama 45-m telescope. Interestingly, the $NH_3$ dense region has a linewidth of only ~ 0.2 km s$^{-1}$ but the CS surrounding gas has a linewidth of ~ 0.8 km s$^{-1}$. This indicates that the turbulent motions are dissipating in dense region. Taking into account the fact that TUKH122 is chemically evolved and the turbulence is almost dissipated within the core, we suggest that this core is on the verge of star formation.

In the observations using the Nobeyama 45-m telescope, we detect not only the quiescent thermal component but also a turbulent wing component in $NH_3$ (J,K=1,1), simultaneously for the first time towards this core. The detection of both $NH_3$ quiescent and turbulent components may indicate a sharp transition from the turbulent parent cloud to the quiescent dense core. This chemically evolved dense core (initial conditions of star formation) may be cold (~ 11 K) and coherent (~ 0.3 km s$^{-1}$).