論文の内容の要旨

論文題目: Kinematics of dense cores and surrounding materials in Taurus and Lupus star-forming regions
(おうし座とおおかみ座星形成領域における高密度コアの運動)

氏名 : 清兼 和紘

In early phase of star formation, angular momentum distribution of a natal core is crucial to determine the evolution of the core. Since there is a large gap of the specific angular momentum between a dense core and a star/disk system, the excessive angular momentum must be converted to orbital angular momentum of a binary or must be removed by a jet/outflow. Rotation yields a velocity gradient, and then one method searching for rotation is a least square fitting of the velocity gradient assuming a rigid rotation, called to a velocity gradient fitting, and it is known that the specific angular momenta of dense cores, $j(= J/M)$, have a relation of $\propto R^{1.6}\ \mathrm{km\,s^{-1}\,pc}$ where R is core size. Recently, high sensitivity mappings of nearby molecular clouds in far-infrared and submillimeter bands with Hershel and AzTEC/ASTE show ubiquitous existence of the filamentary structures with 0.1-pc uniform width. It is important to investigate dense core formation from large scale structure via fragmentation.

I present an observational study of dense cores in Taurus and Lupus Molecular Clouds using the NRO 45 m and the Mopra 22 m telescopes with the ^{13}CO(J=1–0), C^{18}O(J=1–0), $\mathrm{N_2H^+}$(J=1–0), and $\mathrm{HC_3N}$(J=10–9) emission lines. These lines have different critical densities of 10^3 to $10^5\ \mathrm{cm^{-3}}$, and then these lines can probe kinematics of the molecular gas with different densities.

There are four $\mathrm{N_2H^+}$ dense cores in Taurus and six $\mathrm{N_2H^+}$ dense cores in Lupus whose sizes, masses, and velocity widths are in the range of 0.02 - 0.05 pc, 0.27 - 0.44 km s^{-1}, and 0.9 - 1.9 M$_\odot$, respectively. Each $\mathrm{N_2H^+}$ core mass is comparable to the virial mass and thus these cores are physical, not transient objects. The dense cores exhibit a velocity gradient. From the fitting, the velocity gradients were derived to be 0.9 - 4.7 $\mathrm{km\ s^{-1}\ pc^{-1}}$, which have the centrifugal radii of a few au to a few handred corresponding to a known size of protoplanetary disks. Since a outflow axis of protostellar sources in most cases is perpendicular to the velocity gradient, the gradient presumably represents the rotation motion of the dense cores. The rotational axis determined by the velocity gradient of each dense core is randomly directed compared with locally elongated direction of the filaments. It is suggested that the rotational axis of the dense cores in Lupus will be determined by local physical conditions such as turbulence.

I found that different density tracers show different velocity gradients at least in a case of Lup1 C3 and C4. The relatively lower density tracer of C^{18}O shows the large-scale motion in

the filament and the higher density tracer of HC_3N or N_2H^+ shows the rotational motion in the cores. The ratios of the non-thermal velocity dispersion $\sigma_{\rm nth}$ to the sound velocity $c_{\rm s}$ were obtained as $\sigma_{\rm nth}/c_{\rm s}$ $\sim$ 1-2 in $C^{18}O$ and $\sigma_{\rm nth}/c_{\rm s}$ $\sim$ 0.7 in N_2H^+, suggesting that $C^{18}O$ traces supersonic turbulent motions around the dense cores while N_2H^+ and HC_3N trace subsonic turbulent motions within dense cores. As one of kinematics in a filament in present studies, it is suggested to experience a fragment motion along the filaments, which will cause oscillation of densities and centroid velocities with a λ/4 phase shift. No such feature is identified in my samples and fragment motion along filament elongation is not seen universally in low-mass star forming regions. Then, I suggest that there are bimodal evolutional paths with various degree of turbulence. One is that there is an intermediate stage as velocity coherent filaments of multi-fibers from a supersonic turbulent filament to dense cores. The other is that a supersonic turbulent filament would form directly coherent dense cores.

In addition to the velocity gradient fitting, I invented a method to derive the two dimensional specific angular momentum distributions, which can provide the angular momentum and the direction as a function of radius. Interestingly, the directions of the specific angular momentum in L1527 are changing from inner core ($0.01\,{\rm pc} <$ r $<0.02\,{\rm pc}$, P.A. $= +90^\circ$) to outer core ($0.02\,{\rm pc} <$ r $<0.07\,{\rm pc}$, P.A. $= -150^\circ$), while the direction in B335 is almost constant within the core. The rotation axis in the inner core is roughly perpendicular to the outflow axis in both cases. I suggest that the rotational axis of L1527 change at $r \sim$ 0.02 pc, which may explain a deflected molecular outflow observed in several cases.

I searched for dense cores with high resolution of molecular line observations covering 0.01 to 0.1 pc , leading to the following star formation scenario. Filaments are one of the evolutional stages from molecular clouds to to stars through dense cores. In filaments, the surrounding gas traced by $C^{18}O(J=1–0)$ has the supersonic velocity dispersion in a case, and the dense cores traced by $N_2H^+(J=1–0)$ or $HC_3N(J=10–9)$ are located on a state of velocity-coherent within the supersonic turbulent surrounding gas, suggesting that the turbulence will decay during the formation of dense cores. The rotational axes of the dense cores determined by the velocity gradients are not correlated with the directions of filament elongation. Within a core, the rotational axis could change under some situations, but the rotational axis will connect to the inner disk and the outflow direction. Comprehensively, those will be related to evolutions from molecular clouds to stars via filaments and dense cores.