RMHD Simulations of Low-Mass Star Formation Processes

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A first core is a transient object formed in the early phase of star formation. It mainly consists of molecular hydrogen and is in quasi-hydrostatic equiribrium by gas pressure and rotation. This object evolves under the accretion from the envelope, and it begins dynamical collapse due to H_2 dissociation when the central temperature exceeds about 2000 K (the second collapse). The lifetime of a first core is short, about several thousand yrs, but it plays a critical role in star formation processes because it is related to important phenomena such as circumstellar disk formation, binary fragmentation, bipolar molecular outflow, and so on. First cores have not been observed yet since it was theoretically predicted by Larson (1969), but recently several candidates are reported. Now, it is expected that we can observe first cores directly by ALMA.

We performed radiation magnetohydrodynamic simulations of star formation in a rotating magnetized cloud core using our newly developed code[1]. We found that the mass, size and lifetime of the first core are 1.5–2 times larger compared to previous simulations without radiation transfer, due to shock and radiation heating. On the other hand, the structure and velocity of the outflow driven by magnetic fields do not differ significantly. Incorporating radiation transfer is crucial to discuss the stability and observational properties of first cores.

Formation of ~1 $M_\odot$ stars is well studied so far, but, it is well known that there are rather larger number of smaller molecular cloud cores and stars. Some of first core candidates recently reported are also suggested to be less massive, ~0.1 $M_\odot$. Motivated by these facts, we investigated the evolution of the first core in a very lowmass molecular cloud core whose mass is 0.1 $M_\odot$ using RHD simulations[2]. We found that the first core in the very low-mass molecular cloud core evolves slowly under the influence of radiation cooling, and lives significantly longer compared to fiducial 1 $M_\odot$ cases, at least more than 14,000 yrs. This evolution is qualitatively different from that of typical 1 $M_\odot$ models. This result suggests that first cores may be more common than previous predictions. We calculated the observational properties of this model, and showed that it is faint but observable with ALMA and Herschel. We also presented a strategy to observe such a first core and distinguish it from other evolutionary phases.

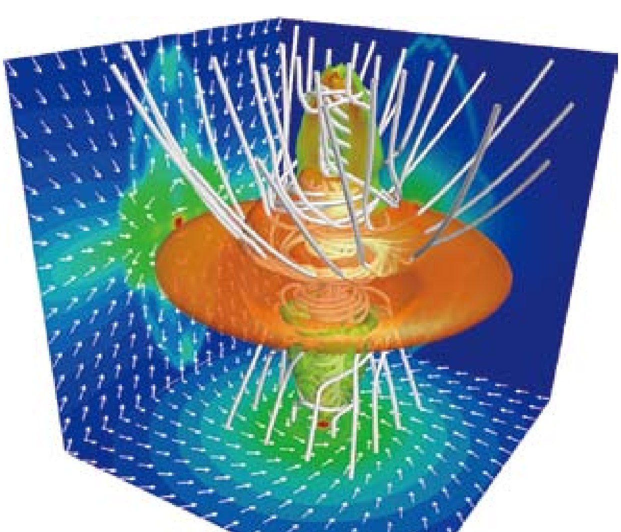

Figure 1: A bipolar outflow is launched from the first core. White lines are magnetic field lines.

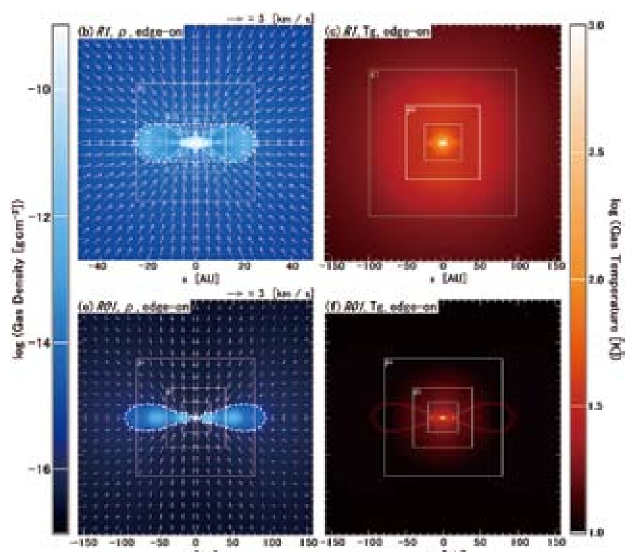

Figure 2: Cross-sections of first cores in 1 $M_\odot$(top) and 0.1 $M_\odot$ (bottom) molecular cloud cores (left: density, right: temperature). In the low-mass model, almost all the gas in the cloud core quickly accretes onto the first core and the envelope becomes very thin. The low-mass model is significantly colder than 1 $M_\odot$ model because of weak accretion and efficient radiative cooling.

References

[1] Tomida, K., et al.: 2010, *ApJ*, **714**, L58.
[2] Tomida, K., et al.: 2010, *ApJ*, **725**, L239.