論文の内容の要旨

論文題目

Mid Infrared Studies of Massive Star Formation

(中間赤外線を用いた大質量星形成の研究)

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Massive stars, with masses larger than 8 $M_\odot$, are ones of the most important sources for dynamical and chemical evolutions in the universe. In spite of the importance of the massive stars, their formation processes have not been well understood. One of the most serious problems is that massive clouds are gravitationally unstable in early collapsing phases. The thermal Jeans masses in infrared dark clouds (IRDCs), considered as their parental dense clouds, are estimated as about 1 $M_\odot$. This implies that the mass is too small to make a massive core and eventually a massive star. Certain mechanisms producing additional inner pressure to overcome a self-gravity of a massive collapsing cloud (CC) in the IRDC is required. One of the possible mechanisms to produce the additional pressure is heating of the gas, which increase thermal pressure of the gas. For example, the gas with a temperature of higher than 40 K can physically support the massive CC with a mass enough to form a massive star against the self-gravity. Among various heating sources, radiation by young stellar objects (YSOs) in the IRDC is considered as a promising one because it could serve as a universal source without invoking any external objects.

We focused on the highest mass YSO in the IRDC because it most effectively heats the IRDC due to its largest luminosity among the YSOs in the IRDC. According to simple estimation, the radiation by a higher intermediate mass YSO (HIYSO; defined as a YSO with a mass of 5 to 7 $M_\odot$ in this work) is required to heat the gas with a mass of 8 $M_\odot$ up to 40 K in total. When the HIYSO already exists before the formation of the massive CC in the IRDC, the radiation by the HIYSO would heat the gas sufficiently. This means that the massive young stellar object (MYSO) is expected to be generally accompanied by the older HIYSO within 0.1-pc region, corresponding to the heating area of the HIYSO radiation. However, it has not been observationally confirmed. To examine whether the star formation sequence between the HIYSO and the MYSO within 0.1-pc size region has such a tendency or not, information of an age and a mass of individual object are strongly desired.

In this work, three massive star forming regions, M8E, RAFGL 6366S, and IRAS 18317-0513, have been observed at the mid-infrared wavelengths, including 31- and 37-micron bands, to examine the star formation sequences between HIYSOs and MYSOs. Our developed mid-infrared camera MAX38 mounted on the miniTAO telescope has been used for this study. The observations have brought us the first images of these regions at longer than 30-microns from ground. The spatial resolution in our observations achieves approximately 8 arcsec at 31 microns and 9 arcsec at 37 microns which is the highest resolution among the other observations carried out so far. Images of all these 0.1-pc size regions, which have achieved enough high spatial resolution to resolve individual objects, have been successfully obtained. These images have enabled us to measure an infrared luminosity of each object separately.

Individual spectral type and stellar mass have been estimated from the derived luminosities using a stellar model. In the M8E and RAFGL 6366S regions, it has been found that the objects associating with UCHII regions have relatively lower masses than the other objects. Because less massive YSOs are expected to have longer evolutional timescale, they may form earlier and more massive objects latter. This tendency has also been confirmed by a quantitative age estimation of each object. Furthermore, a literature survey has been carried out to extend the number of samples. The similar tendency has also been found in one region out of three. In total, such a tendency has been confirmed in three out of six regions and probabilities of existence of this tendency have been left in the other three regions. This suggests that the radiative heating by the previously formed HIYSO helps the formation of MYSO in the massive star forming regions.

Furthermore, we have estimated the gas temperature and the mass of the heated gas using a simple cloud model under assumption of dust thermal equilibrium. It has been suggested that the radiative heating by the HIYSO can increase the gas temperature enough to form the MYSO in a certain case within a possible range of a luminosity and a temperature of the HIYSO. It also has been suggested that the increased mass of CC, assuming that it is equal to the Jeans mass, from the radiative heating by the HIYSO almost corresponds to the mass of the MYSO in a certain case.

This work may provide the first observational evidence that the radiative heating by the previously formed HIYSO induces the formation of the MYSO. This result also suggests speculation that mass of newly formed YSOs in the IRDCs always increase from the first-formed low-mass YSOs to finally-formed MYSOs due to the radiative heating by the previously formed YSOs in the IRDCs. Detailed theoretical models of the radiative heating in the IRDCs and our planning future large survey will give further information of the star formation sequences between HIYSOs and MYSOs and the effect of the radiative heating by the HIYSO. They may also reveal the universality of such star formation sequences with more extended mass ranges.