Investigation of Property of Massive Star Clusters by mini-TAO, TAO and *SPICA*

Hidenori Takahashi,[1] Masuo Tanaka,[1] Shin-ichiro Okumura,[2] and TAO team

[1] *Institute of Astronomy, The University of Tokyo, Japan*
[2] *Bisei Spaceguard Center, Japan Spaceguard Association, Japan*

ABSTRACT

We built up a new observation system for investigation of massive star clusters. The tool is NIR imaging photometry by broad- and narrow-band filters installed in Atacama Near-InfraRed camera (ANIR). The observations of massive star clusters were carried out with mini-TAO 1 m telescope. As the results, almost all of known Wolf-Rayet (WR) stars or luminous-blue variables (LBVs) were confined and new candidates of progenitors of supernovae (SNe) were detected. Color-color diagram ([*N207*/*Ks*] vs [*N187*/*Ks*]) made from the images clearly shows a zone of 1.87 μm excess due to He II and Paschen-alpha emission that indicates WN-type WR stars and LBVs, and a zone of 2.07 μm excess due to C IV emission from WC-type WR stars. In other words, we found that various types of massive stars can be classified as zones on the diagram. Furthermore we will be able to reveal not only buried WR stars but also the constituent, age and evolution of massive star clusters. Identification of the components of clusters with mini-TAO, TAO 6.5 m and *SPICA* gives significant information to clarify the history of star formation (the birth and the evolution) of massive star clusters.

1. RESEARCH AND AIM : IMPORTANCE OF MASSIVE STARS

The Wolf-Rayet (WR) stars are thought to be the progenitors of supernovae. In addition, other types of massive stars are characterized by the generation and release of a variety of metal and release of enormous energy from them. Therefore, detail examinations of massive stars provide a significant information about not only progenitors of the supernovae but also the evolution of the interstellar medium and galaxies. However, the lifetime of massive stars is short and they changes their types in a short period of time. In addition, it is considered to be formed in an environment surrounded by a large amount of gas. That is, there are many mysteries in their birth and the evolution due to large extinction. For example, environment when they are formed, initial mass function (IMF) of a massive star cluster, the amount and mechanism of mass loss, discrepancy in the number of WR stars obtained in simulations and observations, and so on. The aim of our research is to discover new massive stars and to elucidate the evolutionary scenario of massive star clusters.

2. CURRENT OBSERVATIONS AND RESULTS

2.1. Observation

We propose near-infrared spectroscopic imaging observations, i.e, application of narrow band filters dedicated to emission lines characteristic of massive stars at wavelengths with less extinction, and efficient point source photometry by large format array.

The primary instrument for our purpose is ANIR (Motohara et al. 2008) with mini-TAO (The University of Tokyo Atacama Observatory; Minezaki et al. 2010) located at the summit of Cerro Chajnantor, an altitude of 5640 m at Atacama in northern Chile. ANIR is a simple imager that covers from 0.9 to 2.5 μm with four broad-band and four narrow-band filters. Owing to the high altitude and extremely low precipitable water vapor of the site, we can observe stably even 1.87 μm (including He II and Paα emission lines) range. By inserting a dichroic mirror in the front of the dewar window, it is also possible to carry out optical-NIR simultaneous imaging. NIR imaging observations of massive star clusters within Galaxy and LMC have been done by ANIR.

2.2. Color-color Diagram

We show the observational results of 3 massive star clusters near the Galactic center (GC): Quintuplet cluster, Arches cluster, and Sgr A* cluster (Figure 1), by *Ks*, *N187* and *N207* filters installed in ANIR. The latter 2 filters are mainly designed for the detection of emission lines from massive stars. After photometry for point sources of each band, color-color diagram are depicted (Figure 2). Based on the position of each source in the diagrams, we can classify the type of the detected sources. In this figure, WC type WR stars with [C IV] 2.07 μm and LBV or WN-type WR stars which are characterized by He II lines are distributed on right (-top) quadrant and central top area, respectively. In addition it is possible to detect the “red” objects further the lower left. Finally almost all cataloged objects are detected in this diagram. Further unidentified point sources that we found could be new massive stars.

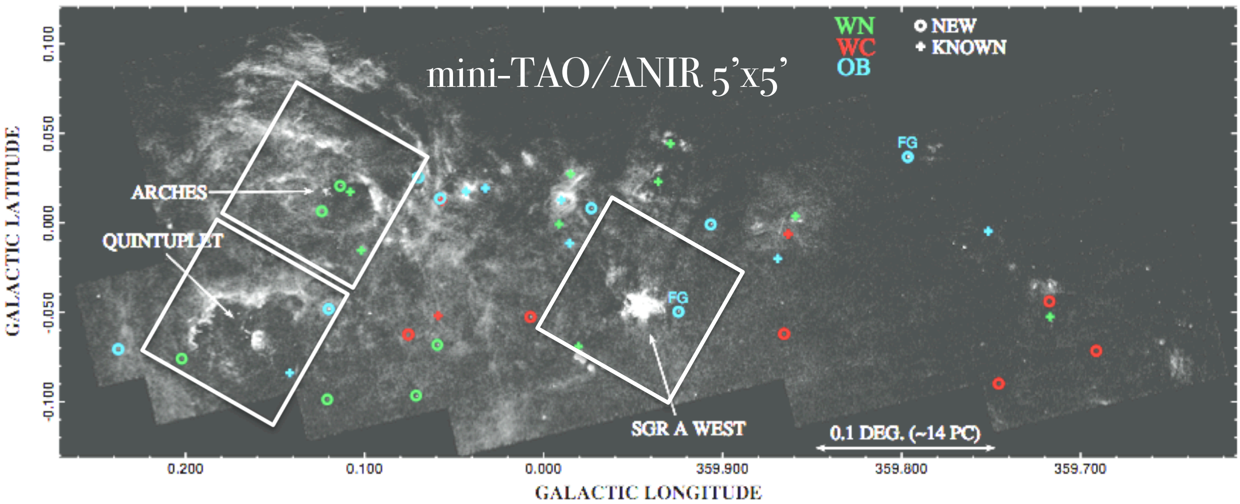

Figure 1. Location of our three observed areas near galactic center (5.1′=11.9 pc for $R0 = 8.0$ kpc) overlaid on the Paα image by Mauerhan et al. (2010) (39′×15′ = 91×35 pc).

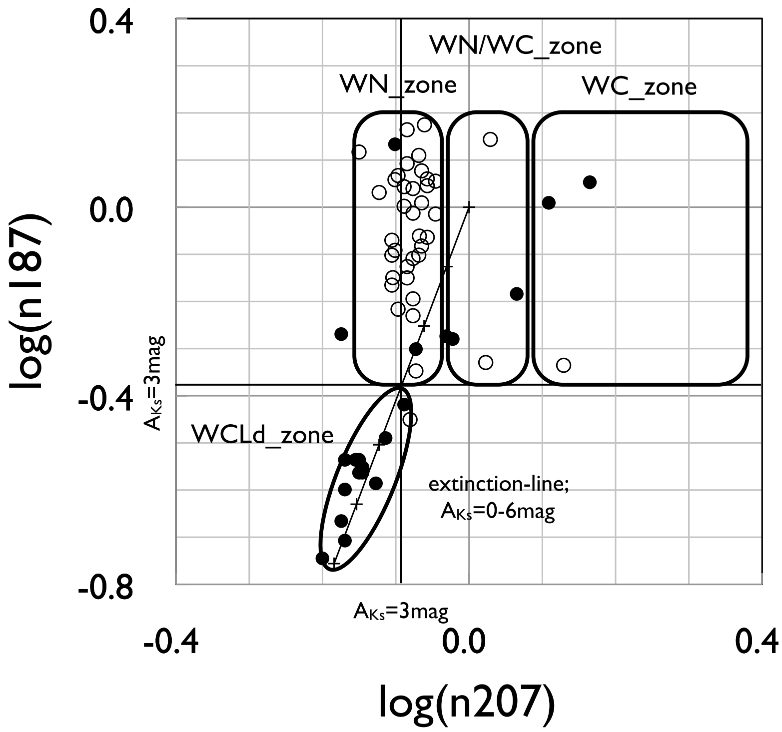

Figure 2. The known WR stars (19, 21, and 19 WRs of Sgr A*, Quintuplet, Arches cluster area, respectively) plotted on the log(*n207*) vs. log(*n187*) diagram. Open and closed circles denote WN (including WN/WC) stars and WC stars, respectively. Each type of WR stars is distinguished by a zone on the diagram.

2.3. **Detailed Classification by Type of Stars**

For example we show the relations between the extinction-corrected *Ks* magnitude and the excess of log(*n187*) (*n187* means the normalized *N187*/*Ks* ratio) for the WN and WN9/Ofpe stars in the three GC clusters in Figure 3. The absolute *Ks* magnitude (corresponding to the extinction-corrected *Ks*) is indicated above the diagram. WN stars and WN9/Ofpe stars clearly show different sequences in this diagram. That is, WN sequence is located to the right of the figure. As the absolute *Ks* magnitude becomes bright, the excess increases. In addition, the trend is the same for WN9/Ofpe stars, however the sequence is shifted to the left. On the other hand, a promising trend was not observed for the O-type stars, the excess value indicates a constant value for absolute *Ks* magnitude.

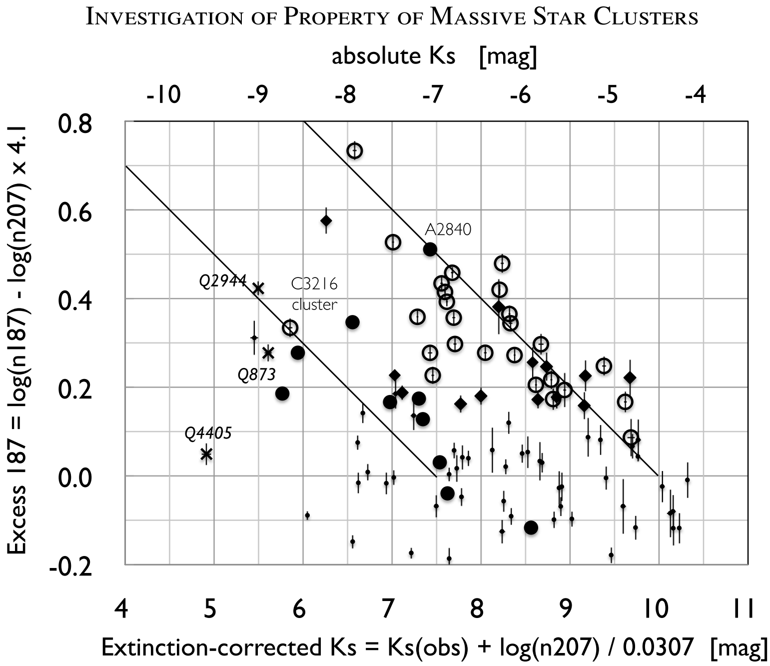

Figure 3. The relations between the extinction-corrected Ks magnitude and the excess of log($n187$) for the WN and WN9/Ofpe stars in the three cluster areas. Open and closed circles denote WN and WN9/Ofpe stars, respectively, and black dot denotes O-type stars (possibly supergiants). Cross denotes three LBV, and black diamond denotes the candidates of WN (or WN/Ofpe) stars detected on our images. The absolute Ks magnitude (extinction and distance modulus are considered) is indicated above the diagram.

3. FUTURE OBSERVATION PLAN

3.1. NIR Survey Observation and Follow-up Spectroscopy

We plan the equipment of narrow-band filters *N187*, *N207*, *N218* and *Ks* broad-band in Simultaneous-color Wide-field Infrared Multi-object Spectrograph (SWIMS; Konishi et al. 2012) for TAO 6.5 m telescope. First, we will perform the classification of the tribe, the detection of known components of clusters, and the picking-up candidates of unknown massive post-MS by these filter sets. Next, the spectroscopic observations will be carried out using a spectroscopic function of SWIMS. As a result, investigation of the nature of the candidates will be achieved. Through the wide area survey of the northern and southern sky with the Subaru telescope (2015–2017) and TAO (2017~), respectively, the exploration of survey of unprecedented area and the production of near-infrared catalog of massive stars will be achieved.

3.2. Research with *SPICA*

It is difficult to estimate the age of a star cluster. Some candidates of the massive post-MS (WR, LBV, BSG, YHG, etc...), MYSOs, and MIRAs are picked up by NIR imaging. The massive stars such as WR are at least 3 Myr old. How many massive stars exist in the cluster or near the cluster and how old are they? That is, to investigate components of the clusters and their lifetimes offers important information for the birth and the evolution of (massive star) clusters. *SPICA* (Nakagawa et al. 2011) has an important role for picking up multi components of a cluster by wide range imaging capability. The observation plans (bands and targets corresponding to each instrument) are shown in Table 1.

Table 1. Observation plans

Observation	Instruments	Targets or purpose
NIR Narrow-band Imaging	mini-TAO/ANIR	Search for post MS
MIR (5–10 μm) Imaging	MCS/WFC-S & FPC/FPC-S	Pick-up 500–1000 K object
NIR Spectroscopy	SWIMS@Subaru, TAO	Classification of type of objects

This work is supported by Ministry of Education, Culture, Sports, Science and Technology of Japan, Grant-in-Aid for Scientific Research
(17104002, 20040003, 22253002, and 22540258) from the JSPS.

REFERENCES

Konishi, T., et al. 2012, vol. 8446 of SPIE Conf. Ser., 84476P
Mauerhan, J., et al. 2010, ApJ, 725, 188
Minezaki, T., et al. 2010, vol. 7733 of SPIE Conf. Ser., 773356
Motohara, K., et al. 2008, vol. 7014 of SPIE Conf. Ser., 70142T
Nakagawa, T., Matsuhara, H., & Kawakatsu, Y. 2011, vol. 8442 of SPIE Conf. Ser., 84420O