論文の内容の要旨

Study of Bulge Properties in Local Luminous Infrared Galaxies Based on Ground-based Paα Imaging Survey

（水素パッシェンα輝線サーベイ観測による近傍高光度赤外線銀河バルジの研究）

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In recent years, many researches suggest that there are two types of bulges found at the center of galaxies, which are called “classical bulges” and “pseudobulges”. The classical bulges are dynamically hot, supported by stellar velocity dispersion rather than their systemic rotational motion, and characterized by steep increase in density towards their centers. In addition, they are red in color, old in population, high in metallicity and in α/Fe ratio. Also, it is suggested that their positions in the fundamental plane form a continuous sequence with those of elliptical galaxies. On the other hand, the pseudobulges are dynamically cold, supported by stellar systemic rotation, and have flat shapes resembling those of exponential disks. Also, they can be identified as outliers in the fundamental plane and generally have younger stellar populations than classical bulges. Theoretically, the classical bulges are considered to be formed by major merger processes, or by collapse of giant clumps in primordial disks to remove their angular momentum. Ellipticals are also considered to be formed by similar processes but they have poor molecular gas with dry merger. On the other hand, the pseudobulges are considered to be built by a secular evolution. From these results, the classical bulges and the pseudo-bulges are considered to have different formation processes, where the classical bulges are formed by drastic external factor such as major merger processes, which are similar process expected for the formation of ellipticals, and the pseudobulges by a secular evolution. However, there are few observational studies to verify the formation scenario of bulges and ellipticals.

The aim of this paper is to verify observationally the formation scenario of bulge drawn in theory, and to understand the formation process of bulges. We therefore focus on LIRGs in the local universe, which are ideal laboratories for studying bulge formation, because half of them are non-irregular galaxies where their bulge type can be evaluated, and they are considered to be current formation sites of bulges with on-going starburst.

However, LIRGs are affected by a large amount of dust, typically associated with the regions of active star formation. Therefore, optical hydrogen recombination lines that are direct probes of massive stars such as Hα and Hβ are easily attenuated by the dust. Wherein the hydrogen Paα emission line (1.8751 μm) is a good tracer of the dusty star-forming region because of its insensitivity to the dust-extinction and being the strongest emission line in the near-infrared wavelength range (NIR, $\lambda \sim$ 0.9–2.5 μm), which can reach higher spatial resolution easily than in the MIR and FIR.

However, because of poor telluric atmospheric transmission around the wavelength of Paα due to absorptions mainly by water vapor, no Paα imaging from a ground-based telescope is reported so far.

Therefore, we have been carrying out Paα narrow-band imaging observations with Atacama Near InfraRed camera (ANIR), on the University of Tokyo Atacama Observatory (TAO) 1.0m telescope (miniTAO) installed at the summit of Co. Chajnantor (5640m altitude) in northern Chile. Thanks to the high altitude and the extremely low water vapor content of the site we can stably observe Paα emission line has been observationally confirmed.

We have observed 38 galaxy system listed in *IRAS* RBGS catalog in Paα with a narrow-band filter at 1.91 μm (cz = 2800–8100 km s^{-1}, L(IR) = 4.5×10^{10}–6.5×10^{11} $L_\odot$). Paα fluxes are estimated from the narrow-band images with our newly developed flux calibration method, and find that $SFR(\mathrm{Pa}\alpha)_{\mathrm{corr}}$ which is star formation rate (SFR) obtained from Paα luminosity corrected for effect of dust extinction with Balmer decrement method (Hβ/Hα) shows good agreement with SFR(IR) which is SFR estimated from total infrared luminosity. This result suggests that Paα with dust-extinction correction is sufficient for estimating SFR of whole the galaxy. However, some galaxies have large differences between the $SFR(\mathrm{Pa}\alpha)_{\mathrm{corr}}$ and the SFR(IR), which may be caused by effect of AGNs, strong dust-extinction, or IR cirrus component. We also obtain surface densities of L(IR) ($\Sigma_{L(\mathrm{IR})}$) and SFR obtained from Paα (Σ_{SFR}) for individual galaxies by measuring extension of distribution of star-forming regions within a galaxy with Paα emission line. The range of $SFR(\mathrm{Pa}\alpha)_{\mathrm{corr}}$ in our sample (from 0.6 to 104 $M_\odot$ yr^{-1}) fill the blank of the range of SFR in previous works. We find that most of the sample follow a sequence of local U/LIRGs on the L(IR)-$\Sigma_{L(\mathrm{IR})}$ and SFR-Σ_{SFR} plane. We confirm that a transition of the sequence from normal galaxies to U/LIRGs is seen at $L(\mathrm{IR}) = 8 \times 10^{10}$ $L_\odot$.

Using this sample, we next estimate the properties of two types of bulges (classical and pseudo-bulges). To classify them, we remove 18 irregular galaxies from our sample and perform a two-dimensional bulge-disk decomposition analysis in the K_{s}-band images with a combination of a Sérsic profile as the bulge component and an exponential profile as the disk component. We find that the Sérsic indices of LIRGs have bimodal distribution with a separation of $n_b \sim 2.5$, which is consistent with the separation of bulges in the normal galaxies reported in previous works. Also, B/T increase with increasing Sérsic indices. These results suggest that properties of bulges in LIRGs are same as those of normal galaxies. Also, we measure the extents of distribution of star-forming regions in Paα emission line images, and find that extents normalized by the bulge sizes correlate with Sérsic indices of bulges, suggesting that pseudobulges have extended star-forming regions beyond the bulge, while classical bulges have compact star-forming regions concentrated at the centers of the galaxies. These results suggest that there are different star formation scenarios at work in classical and pseudo-bulges.

Furthermore, our results may support the hypothesis that there are two different modes of black hole feeding, where the growth of black holes and classical bulges are controlled by the same global process with major merging, while that of black holes and pseudobulges are independent or have a weak connection with secular evolution.