（第3号様式）(Form No. 3)

学 位 論 文 要 約
Dissertation Abstract

氏　　名 (Name)　登口 暁

論　文　名: (Dissertation Title) Optical properties of infrared-bright dust-obscured galaxies and discovery of blue-excess dust-obscured galaxies

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Nowadays it is believed that most massive galaxies harbor a supermassive black hole (SMBH) in their nuclei, and the mass of SMBHs reaches up to ~10^9 $M_\odot$. However, it is totally unclear how SMBHs obtained their vast mass. For studying the SMBH evolution, active galactic nuclei (AGNs) have been studied so far because they are extremely bright due to the mass accretion onto a SMBH and thus we can investigate growing SMBHs by investigating AGNs. As a promising scenario for explaining the triggering mechanism of the mass accretion onto SMBHs in AGNs, the gas-rich major merger scenario has been discussed. In this scenario, quasars evolve through the following steps: (1) mergers of gas-rich galaxies with a similar mass, (2) active star formation (SF) obscured by dust, (3) activated AGN obscured by dust, and (4) optically-thin AGNs or quasars, which are the most luminous AGNs. Recently, infrared (IR)-bright dust-obscured galaxies (DOGs) have attracted much attention for understanding the evolution of SMBHs, as they are thought to correspond to the dusty SF and AGN phases. Here the DOG is a special class of galaxies showing an extremely red color between optical and mid-infrared with the selection criterion of $(i - [22])_{\rm AB} > 7.0$. However, the hypothesis of the evolution of IR-bright DOGs to quasars has not been confirmed observationally so far, due to their low number density and to their faintness in optical. In order to examine the evolutionary scenario of DOGs, it is necessary to search for IR-bright DOGs over a wide area, and to investigate their statistical properties observationally.

In this dissertation, a new IR-bright DOG sample is made by utilizing very deep and wide optical imaging data obtained with Hyper Suprime-Cam (HSC) boarded on the Subaru Telescope, near-IR imaging data obtained VISTA Kilo-degree Infrared Galaxy survey, and mid-

IR imaging data obtained *Wide-field Infrared Survey Explorer* all sky survey. In the search area of ~105 deg^2, 571 IR-bright DOGs are selected. The selected IR-bright DOGs show the optical color of $(g-z)_{\mathrm{AB}} = 2.2 \pm 1.0$. The measured optical color of IR-bright DOGs is redder than that of various other galaxy populations at similar redshifts, and the color dispersion of the IR-bright DOGs is significantly larger than that of the comparison samples. Especially, the color of the IR-bright DOGs is much redder than that of ultra luminous infrared galaxies (ULIRGs: 0.4 ± 0.6) and hyper luminous infrared galaxies (HyLIRGs: 0.6 ± 0.5), which are known to be dusty objects with a high IR luminosity. This result suggests that the selected IR-bright DOGs are more deeply covered by dust than other dusty populations of galaxies. In order to understand the origin of the larger color dispersion of the IR-bright DOGs compared with other dusty populations, we classify the IR-bright DOGs into three groups; 51 SF-dominated DOGs, 257 AGN-dominated DOGs, and 263 unclassified DOGs, based on their optical-IR spectral energy distribution, and calculate the $(g-z)_{\mathrm{AB}}$ colors of each group. The derived $(g-z)_{\mathrm{AB}}$ color of the SF-dominated DOGs is 2.5 ± 1.0, while that of AGN-dominated DOGs is 1.8 ± 0.9. Therefore, the large color dispersion of IR-bright DOGs is partly because of the presence of the two different populations in IR-bright DOGs with a systematically different optical color. Although most DOGs show redder optical color then various comparison samples, some IR-bright DOGs have similarly blue $(g-z)_{\mathrm{AB}}$ color to the optically-thin, dust-unobscured quasars (0.5 ± 0.4). Interestingly, ~4 % of the AGN-dominated DOG sample (8 objects) show an extremely blue color in optical (blue-excess DOGs; BluDOGs), albeit they show extremely red color in the optical-IR spectral energy distribution. A possible origin for this blue excess inferred based on their photometric properties is either the leaked AGN light or stellar UV light from nuclear starbursts. Further it is discussed that the BluDOGs are possibly in the transition phase from obscured AGNs to unobscured AGNs.

For better understandings of the blue excess seen in the BluDOGs and also the nature of BluDOGs in the context of the gas-rich major merger scenario, spectroscopic observations for 4 BluDOGs are carried out by using Subaru/FOCAS and VLT/FORS2. The analysis of the obtained spectroscopic data newly revealed the following spectroscopic properties of BluDOGs at $2.2 < z_{\mathrm{sp}} < 3.3$, which is somewhat higher than the typical redshift of DOGs without the blue excess. The rest-frame UV spectra of the BluDOGs show broad ($\gtrsim$2000 km/s) emission lines. The observed broad lines suggest that the nuclear broad-line region (BLR) of BluDOGs is not completely obscured, albeit they show a very dusty nature in their optical-IR SED. Such broad CIV lines seen in the spectra of BluDOGs show a significant blue wing, which is probably more prominent than ordinary SDSS type-1 quasars. This suggests a presence of the powerful nuclear outflow at the spatial scale of the BLR in BluDOGs. The equivalent width (EW) of their BLR lines is very large, EW(CIV)$\sim$150 Å, which is $\sim$6 times larger than SDSS type-1 quasars. Such strong BLR lines cause the flux excess of blue photometric bands in optical. Note that the observed large EWs of BluDOGs are not explained by the so-called Baldwin effect. A possible origin of this large EW is a powerful nuclear outflow in BluDOGs causing a selective obscuration of the nuclear region, as suggested for ERQs. Interestingly, the

Eddington ratio of BluDOGs is close to or higher than 1 (Figure 1). The Eddington ratio of comparison samples including the extremely red quasars (ERQs), *WISE*/SDSS selected hyper-luminous quasars (WISSH) quasars, Hot DOGs, and DOGs, is not as high as that of the BluDOGs. Therefore the mass accretion onto the SMBH in BluDOGs is in the mode of the Eddington-limit or super-Eddington accretion. All of the above results of the spectral analyses support the scenario that the BluDOG is a population of AGNs in the transition phase from the optically thick to optically thin quasars, i.e., in the blowing-out phase during the major-merger scenario for the SMBH evolution. Near-future systematic spectroscopic observations for large samples of IR-bright DOGs will confirm or further develop the picture of the quasar evolution shown in this dissertation.

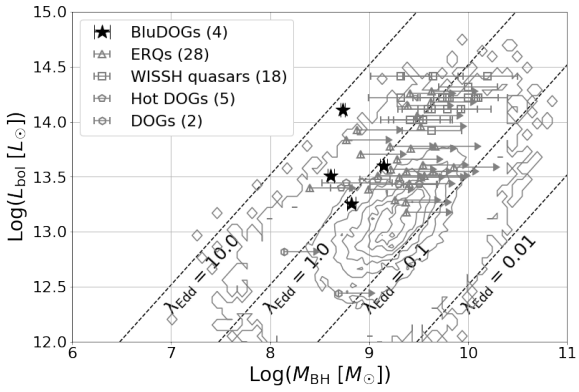

Fig. 1: Bolometric luminosity vs. SMBH mass diagram. The star, triangle, square, pentagon, and hexagon plots denote the BluDOGs, ERQs, WISSH quasars, Hot DOGs, and DOGs, respectively. The contour and dashed lines represent the distribution of the SDSS quasars and a constant Eddington ratio of $\lambda_{\rm Edd} = 0.01$, 0.1, 1.0, and 10.0. The BluDOGs discovered by this dissertation have a high Eddington ratio, suggesting that the BluDOGs are in the most actively evolving phase of SMBHs.