Abstract
Yamada+19 suggest that the fraction of “buried” AGNs in luminous infrared galaxies (LIRGs) increases as the galaxy-galaxy interaction becomes more significant. Here, we have analyzed the broadband X-ray spectra of “non-merging” LIRGs NGC 5135 and UGC 2608, utilizing the data of NuSTAR, Suzaku, XMM-Newton, and Chandra, in order to search for differences in the torus structure from “merging” LIRGs. Applying the X-ray clumpy torus model (XCLUMPY: Tanimoto+19), we find that both sources show similar spectra characterized by heavily absorption with logN_{H}/cm^{2} > 24, and the torus angular-width is < 30°, respectively. Our result implies that AGNs in non-merging galaxies tend to be not deeply buried, in contrast with LIRGs in late merging stages.

1. Obscured AGNs in LIRGs
● Luminous Infrared Galaxies (LIRGs) radiate the bulk of their luminosities in the infrared band (L_{IR} > 10^{11} L_{\odot}).
● Many of them are interacting galaxies. Hopkins+06 predicted that AGNs in the late-stage merging galaxies are deeply buried by gas and dust.
● This scenario is difficult to test because of thick obscuration (Fig. 1). X-ray and Mid-IR observations are useful due to their high penetrating power against obscuration!!

2. Mid-IR Study : Diagnostics of “Buried” AGNs
● To identify whether an AGN is deeply buried, we utilize the ratio of the nuclear 12 µm (Asmus+14) and [O IV] 25.89 µm luminosities. [O IV] line is less affected by dust extinction and star formation activities than the widely used [O III] λ5007 line.

① Swift/BAT sample observed with Suzaku : 16 Seyfert 2s whose X-ray scattering fractions f_{scat} are estimated (e.g., Kawamuro+16).

② 23 local LIRGs (Armus+09) sample
AGNs in early-stage mergers and nonmergers are not buried, while AGNs in late merging stages are deeply “buried”!!

3. X-ray Study : Two Non-merging LIRGs
● To confirm such an evolutionary scenario, it is important to investigate the torus properties (i.e., covering fraction).
● Hard X-ray (>10 keV) observations enable us to detect hidden AGNs, even Compton-thick ones with column densities of logN_{H}/cm^{2} = 24-25.
● Here, we focus on the “non-merging” LIRGs NGC 5135 and UGC 2608 observed with NuSTAR, in order to search for differences in the torus structure from “merging” LIRGs. To investigate the covering fractions of the tori, we utilize the X-ray clumpy torus model (XCLUMPY: Tanimoto+19).

4. Broadband X-ray Spectral Analysis
● These AGNs show similar spectra characterized by heavy absorption (logN_{H2} > 24), and their intrinsic 2-10 keV luminosities are ~5-6 × 10^{43} erg/s.
● Their Eddington ratios (~ 0.1) are smaller than those of AGNs in late-stage merging LIRGs (e.g., Mrk 463, Yamada+18; UGC 5101, Oda+18).
● The torus angular-widths are $< 30^\circ$, implying that these AGNs have moderate covering fractions (not buried!)

Fig. 1 Structures of LIRGs buried by gas and dust.

Fig. 2 Nuclear 12 µm continuum and [O IV] line emission.

Fig. 3 Nuclear 12 µm vs. [O IV] luminosity.

Fig. 4 Nuclear 12 µm and [O IV] emission from the “buried” AGN.

Fig. 5 Nuclear 12 µm vs. [O IV] luminosity for the local LIRGs (Yamada+19).

Fig. 6 Optical images of NGC 5135 (left) and UGC 2608 (right).

Fig. 7 Geometry of XCLUMPY model (Tanimoto+19).

Fig. 8 The best-fit model and spectra of NGC 5135 and UGC 2608. The black, green, cyan, magenta, red, blue crosses represent the NuSTAR, Suzaku/XIS-FI, Suzaku/XIS-BI, Chandra, XMM-Newton/MOS, and XMM-Newton/pn data, respectively. Bottom panels show the residuals in units of 1σ error.