Revealing Compton-thick AGNs in Two "Non-merging" Luminous Infrared Galaxies with Broadband X-ray Observations

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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 $\log N_H/\mathrm{cm}^{-2} > 24$, 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.

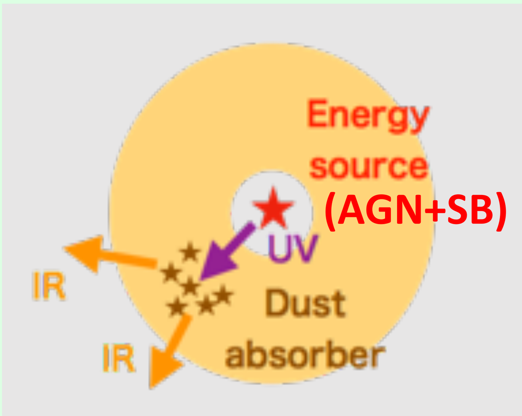

Fig. 1 Structures of LIRGs

- 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).

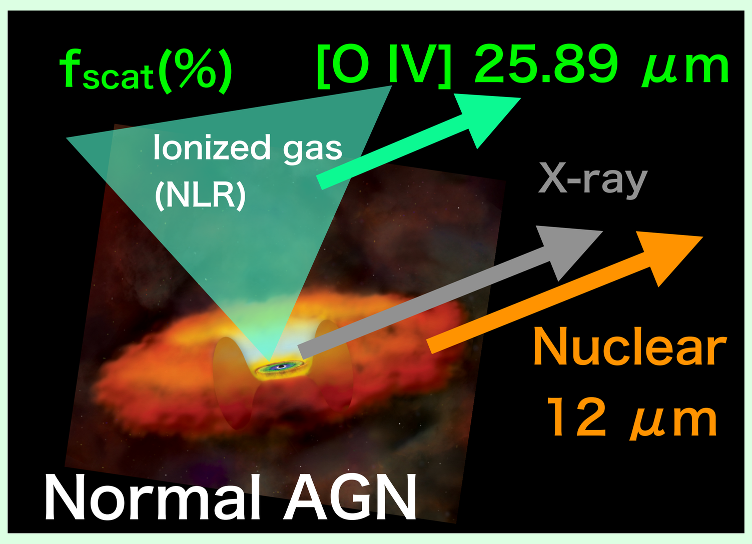

Fig. 2 Nuclear 12 μm continuum and [O IV] line emission.

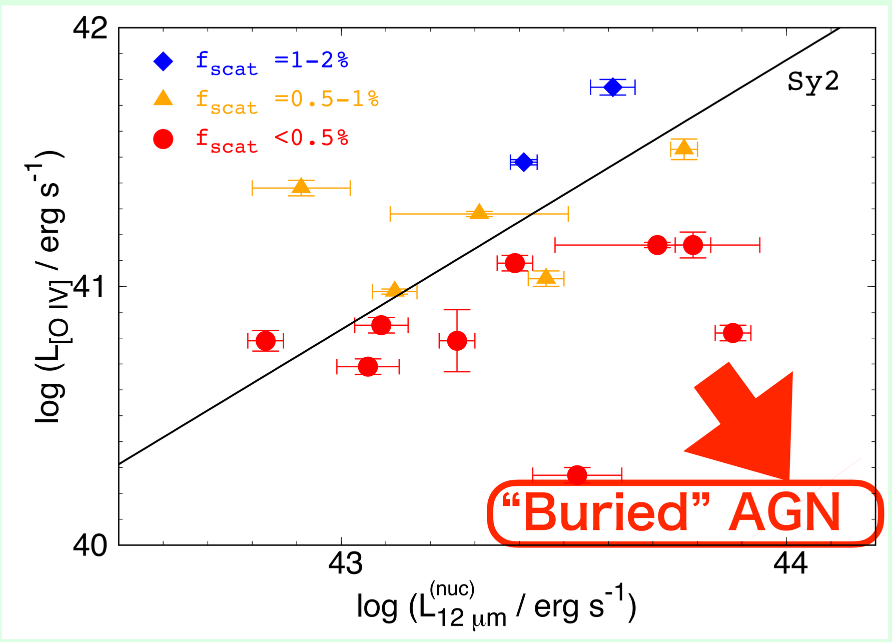

Fig. 3 Nuclear 12 μm vs. [O IV] luminosity.

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"!!

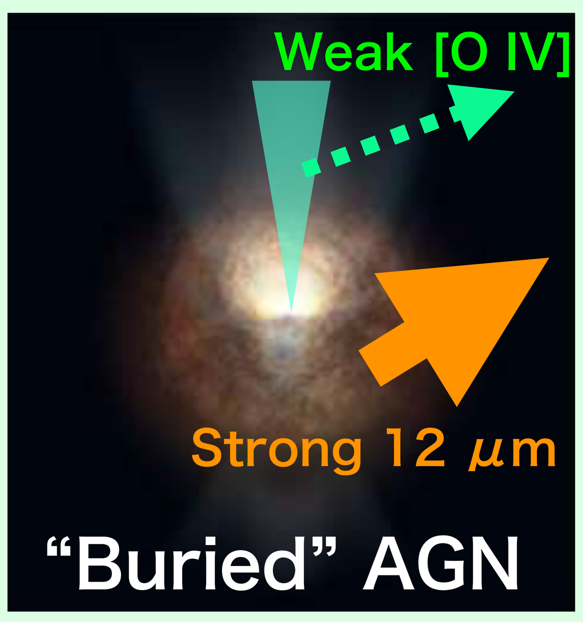

Fig. 4 Nuclear 12 μm and [O IV] emission from the "buried" AGN.

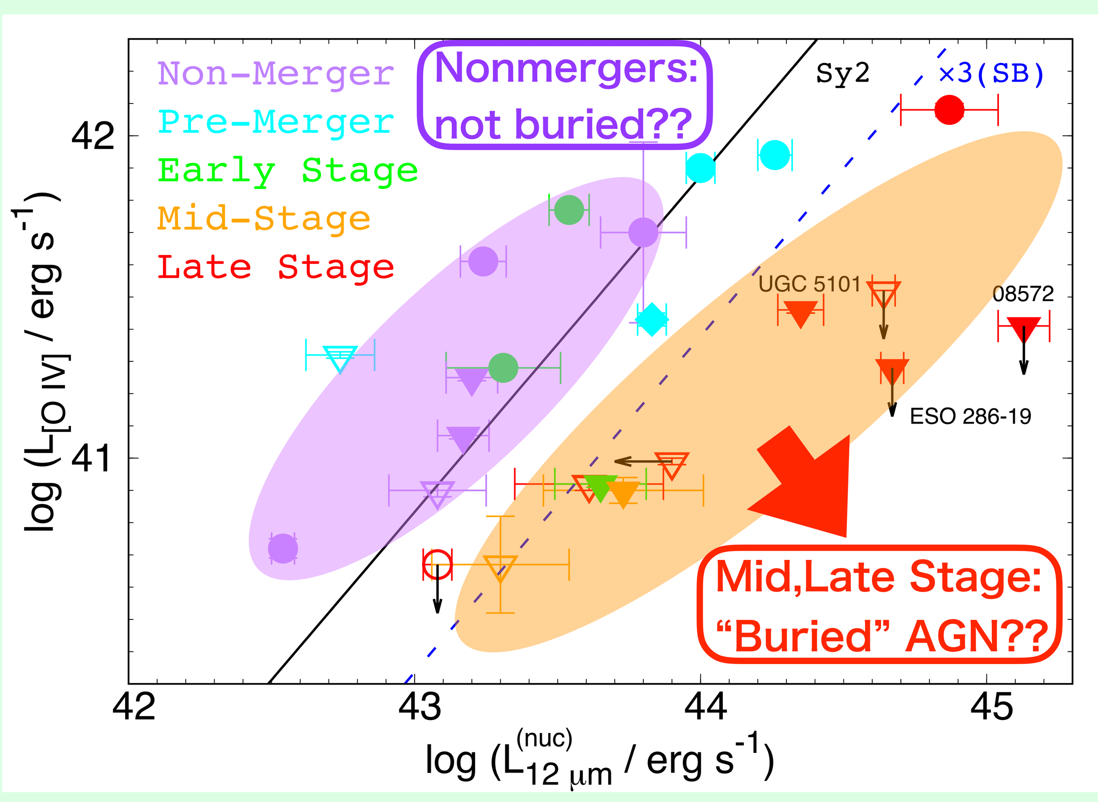

Fig. 5 Nuclear 12 μm vs. [O IV] luminosity for the local LIRGs (Yamada+19).

3. X-ray Study : Two Non-merging LIRGs

- To confirm such an evolutional 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 $\log N_H/\mathrm{cm}^{-2} = 24\text{-}25$.
- 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, Fig. 7).

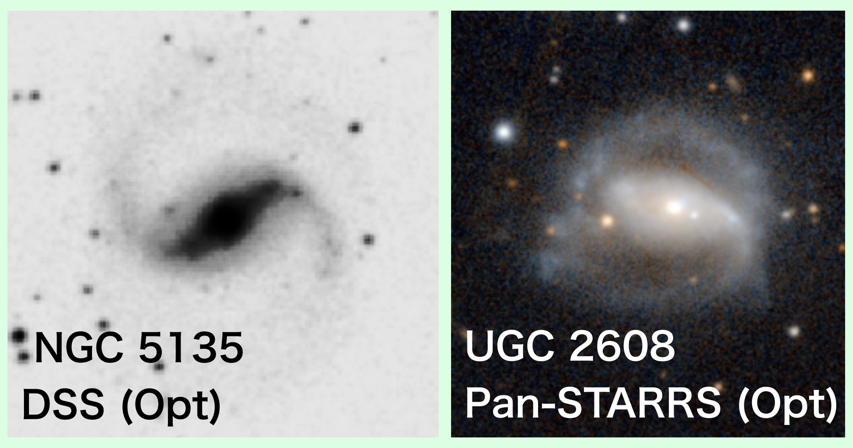

Fig. 6 Optical images of NGC 5135 (left) and UGC 2608 (right).

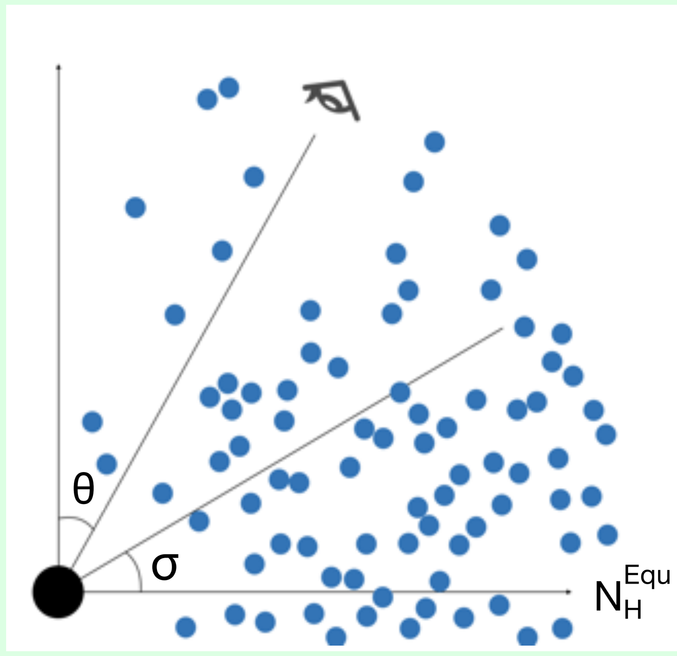

Fig. 7 Geometry of XCLUMPY model (Tanimoto+19).

4. Broadband X-ray Spectral Analysis

- These AGNs show similar spectra characterized by heavily absorption ($\log N_H > 24$), 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 σ < 30°, implying that these AGNs have moderate covering fractions (not buried)!

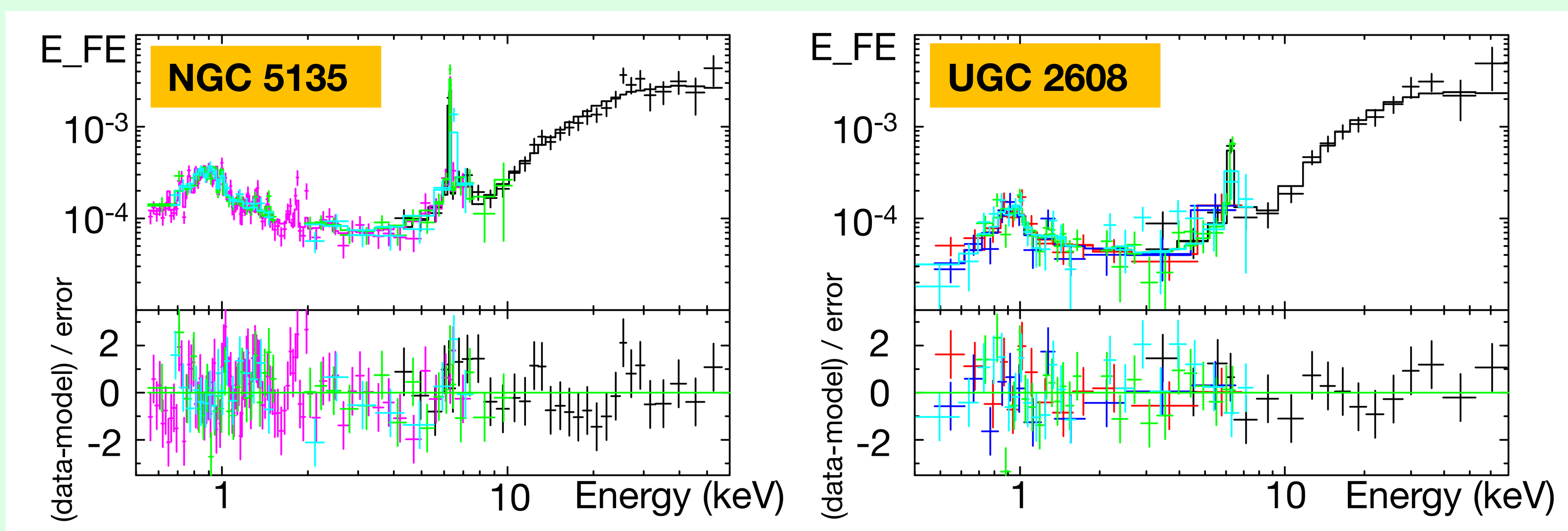

Fig. 8 The best-fit model and spectra of NGC 5135 and UGC 2608. The black, green, cyan, magenta, red, blue crosses represent the NuSTAR, Suzaku/XIS-FI, Suzaku/XIS-BI, Chandra, XMM-Newton/MOS, and XMM-Newton/pn data, respectively. Bottom panels show the residuals in units of 1σ error.