Formation and Evolution of Galaxy Bulges
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^{12}CO observations on narrow-line Seyfert 1 galaxies

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Abstract. In order to investigate how the growth of galactic bulges is accompanied with the growth of central black holes (BHs), we observed molecular gas (fuel for the coming star formation) in possibly young active galaxies, narrow-line Seyfert 1 galaxies (NLS1s). We present the results of pilot observations of ^{12}CO (1→0) line using the Nobeyama Millimeter Array for two FIR-bright NLS1s, ending in the first detection of their CO emission. Corresponding molecular-gas masses $M(H_2)$ of $(1-3)\times10^9$ $M_\odot$ are the 2nd and 4th largest ones among NLS1s. Together with CO data for other NLS1s (including our sub-kpc observations) and for broad-line Seyfert 1 galaxies (BLS1s), we found that NLS1s and BLS1s contain a similar amount of molecular–gas. We do not see a significant difference in $M(H_2)/M_{\rm BH}$ ratios and in $M(H_2)/M_{\rm bulge}$ ratios between NLS1s and BLS1s. The lack of a clear difference in $M(H_2)$ between them indicates either that bulge and BH growth phases are not overlapped or that the duration of star formation is much longer than that of active galaxies.

Keywords. galaxies: active, galaxies: evolution, galaxies: ISM, radio lines: ISM, ISM: molecules

1. Introduction

Mass of galactic spheroid component (galactic bulge or elliptical galaxy itself) is tightly correlated with mass of central black hole (BH) both in normal and in active galaxies (Gebhardt *et al.* 2000; Ferrarese & Merritt 2000; Nelson 2000). The tightness of the correlation indicates that the growth of spheroid mass and that of BH mass ($M_{\rm BH}$) occur almost contemporarily. However, no direct evidence for simultaneous coevolution has been found, and thus its physical origin remains a great mystery.

Here, we notice a subsample of Active Galactic Nuclei (AGNs), narrow-line Seyfert 1 galaxies (NLS1s; Pogge 2000), as possibly young AGNs (Brandt & Boller 1998; Mineshige *et al.* 2000).

2. Results: Molecular Gas Mass in NLS1s and BLS1s

So far, there are only a few NLS1s whose CO lines are detected in the nearby universe. Intending to increase the number of such NLS1s, we carried out pilot observations with the D-configuration of the Nobeyama Millimeter Array (NMA; beam size $\sim 6''$). We selected two FIR-bright, SBb galaxies, IRAS04312+4008 (z=0.02) and IRAS05262+4432 (z=0.03), to observe.

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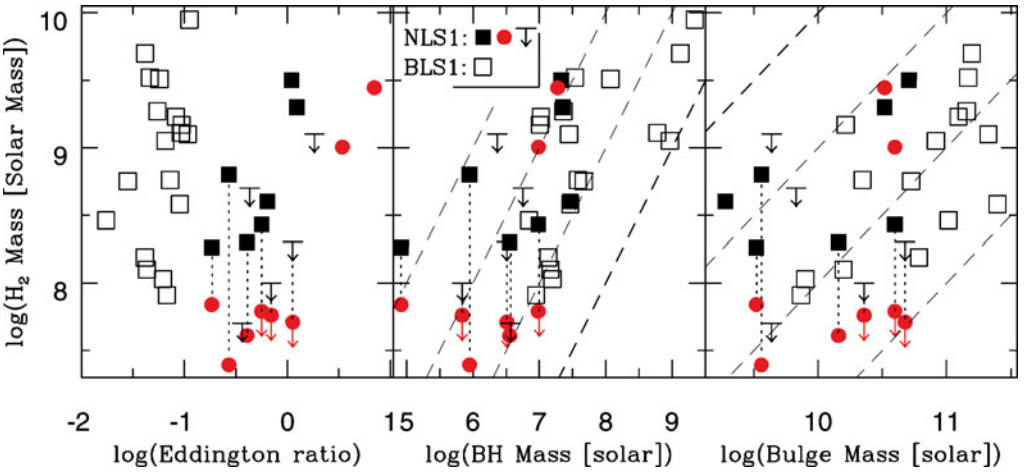

Figure 1. H_2 gas mass associated with host galaxies of NLS1s and BLS1s as functions of Eddington ratio, BH mass and bulge mass. Filled symbols and downward arrows mean NLS1s, while open squares are drawn for BLS1s. Filled red circles indicate our observational data.: Two upper data are collected with $5'' \times 6''$ spatial resolution, while six lower data points are measured with $1.5'' \times 2''$ spatial resolution, with downward arrows meaning 3σ upper limits. We note that BLS1s with no detection of CO emission are not plotted.

The velocity-integrated fluxes from IRAS 04312 and IRAS 05262 are 57 Jy km/s and 62 Jy km/s, respectively, meaning that their molecular-gas masses $M(H_2)$ are $1.0 \times 10^9 M_\odot$ and $2.8 \times 10^9 M_\odot$. These molecular-gas masses are the 2nd and 4th largest ones (to our best knowledge) among NLS1s.

By summarizing the BLS1s and NLS1s detected via observations with over–kpc spatial resolutions (boxes and two upper circles in Figure 1), we found that NLS1s and BLS1s contain a similar amount of molecular-gas. Especially, when we compare the two poplulations at the same $M_{\rm BH}$ and $M_{\rm bulge}$ ranges, we do not see any significant difference. What does this mean then? One instant possibility is that coevolution occurs via numerous short-term epochs: AGNs, whatever young and old, would have similar $M(H_2)$. What if one coevolution epoch nevertheless makes significant increases both in $M_{\rm BH}$ and in $M_{\rm bulge}$, where an object appears as a NLS1 in the early stage of BH growth and eventually varies to a BLS1 later on? In this case, the lack of the difference in $M(H_2)$ between NLS1s and BLS1s indicates either that bulge and BH growth phases are not overlapped or that the duration of star formation is much longer than that of active galaxies.

More details will be presented elsewhere (Kawaguchi *et al.* in prep.).

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