The AGN-starburst connection traced by the nitrogen abundance

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1. Coevolution of galaxies and supermassive black holes

There are some evidences that supermassive black holes (SMBHs) have evolved with their host galaxies (e.g., *M*-σ relation; Marconi & Hunt 2003, ApJ, 589, L21). However, we do not know how the coevolution has been done in the history of the universe. The connection between the active galactic nuclei (AGNs) and star formation activities is one of the most important aspects to understand the coevolution.

2. Connection between AGN and starburst

The relation between black-hole accretion and post-starburst

In the previous studies, it has been reported that the AGN activity, i.e., the mass accretion to the SMBH, is related to the star formation activity. Recent studies on local AGNs have shown that AGN activities and nuclear star formation are not coeval (Fig. 1; Davies et al. 2007, ApJ, 671, 1388). More specifically, the accretion appears to occur in post-starburst nuclei, with a delay of 10^8 years from starburst (Fig. 2). Probably during the active starburst phase powerful supernova explosions expel the circumnuclear gas preventing it to reach the black hole, while the more gentle winds of AGB stars occurring on time scales of 10^8 years are capable of stirring the interstellar matter, making it loose angular momentum and then feed the AGN.

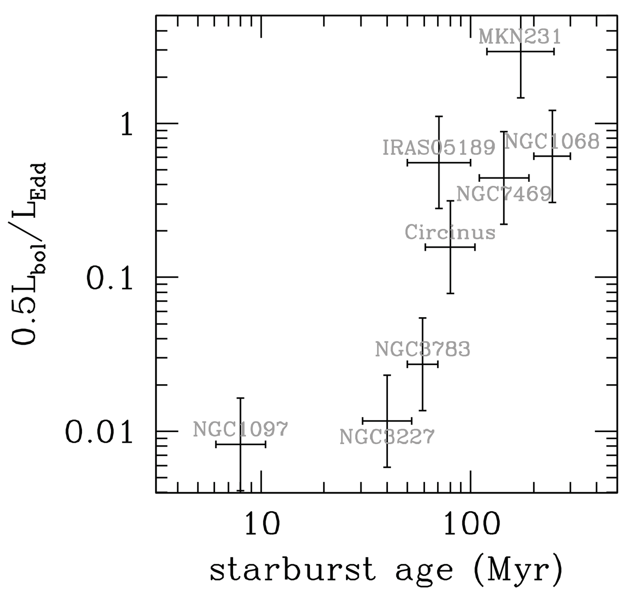

Fig. 1: Graph showing how the AGN activity, i.e., Eddington ratio, might be related to the age of the most recent episode of nuclear star formation (Davies et al. 2007).

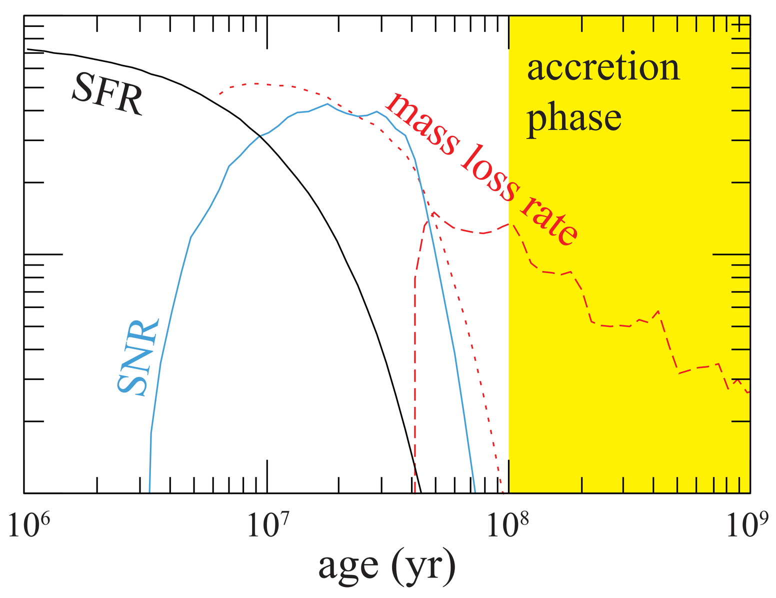

Fig. 2: Prediction based on a star formation model, which is illustrative of a "typical" nuclear starburst (Davies et al. 2007); star formation rate (SFR), supernova rate (SNR), and mass loss rate from stars. The mass loss is split into that due to OB stars, Wolf-Rayet stars, and supernovae (dotted lines) and that due to late-type and AGB stars (dashed lines). The yellow region shows the accretion phase, influenced by mass loss from late-type and AGB stars.

The Eddington ratio and nitrogen abundance relation

By using SDSS spectra of 2383 quasars at $2.3 < z < 3.0$, we investigated the dependence of the emission-line flux ratios as the broad-line region (BLR) metallicity on the Eddington ratio (Fig. 3; Matsuoka et al. 2011, A&A, 527, A100); we measured the emission-line flux ratios of NV/CIV, NV/HeII, (SiIV+OIV])/CIV, and AlIII/CIV, that are sensitive to the BLR metallicity.

As shown Fig. 3, we found that the Eddington ratio depends on the emission-line flux ratios involving NV, while it does not correlate with (SiIV+OIV])/CIV and AlIII/CIV. We suggest that the correlation between the Eddington ratio and the line ratios including NV, is tracing a delay of the mass accretion to SMBHs relative to the onset of nuclear star formation of about 10^8 years reported by Davies et al. (2007), which is the time scale required for the nitrogen enrichment.

This result supports the connection between the AGN activity and post starburst, and means that AGNs in higher accretion phase, i.e., SMBHs in more rapid growth, have more nitrogen-rich gas cloud.

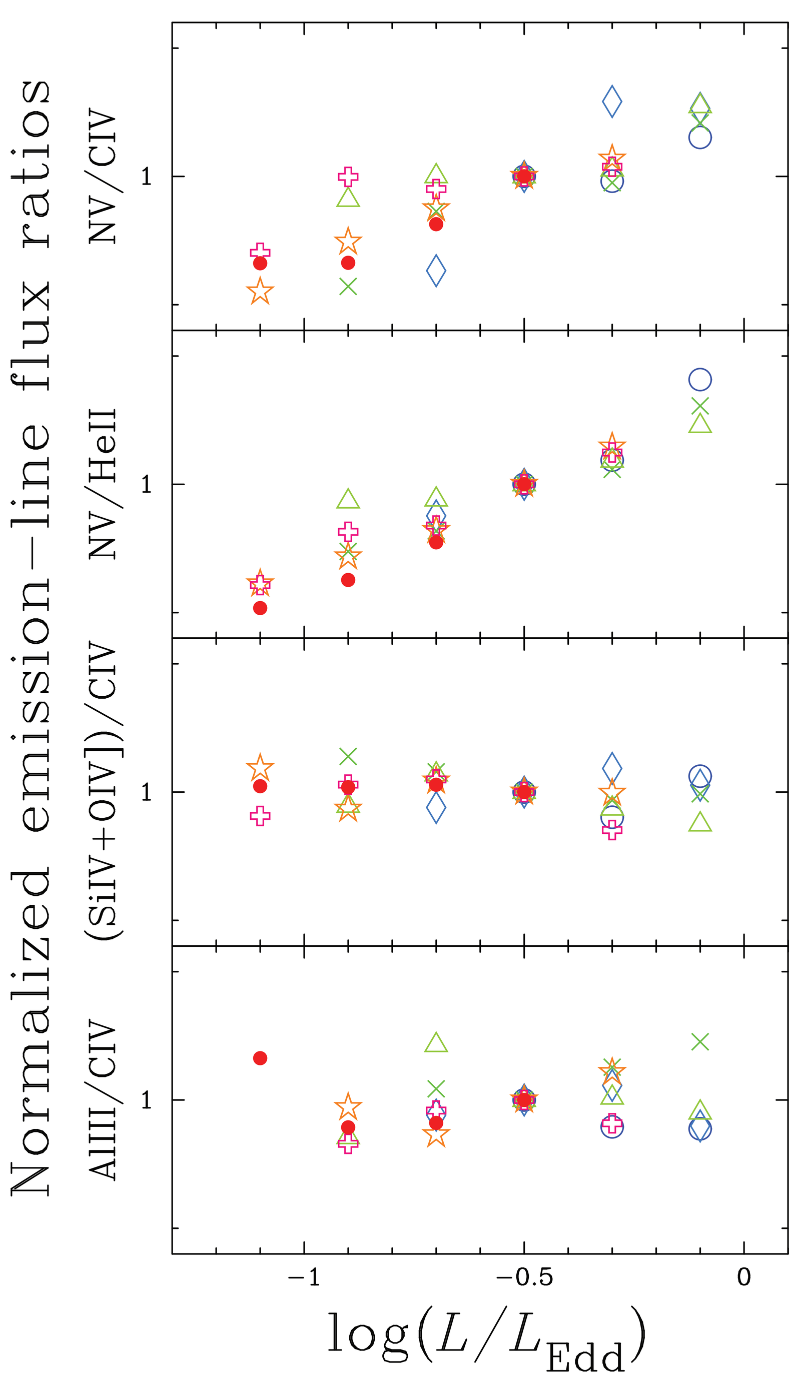

Fig. 3: The correlation between the Eddington ratio and metallicity sensitive emission-line flux ratios. Each symbol shows various BH masses. These emission-line flux ratios are normalized by the values at $-0.6 < \log(L/L_{\rm Edd}) < -0.4$ to minimize the effect of black hole mass on the relation between the Eddington ratio and the flux ratios. There is a correlation between the Eddington ratio and emission-line flux ratios involving NV line, but other emission-line flux ratios does not show the dependence on the Eddington ratio (Matsuoka et al. 2011).

3. Nitrogen-loud quasars

Osmer & Smith (1980, ApJ, 42, 333) discovered an unusual quasar (Fig. 4) that has prominent emission lines of nitrogen; this is called nitrogen-loud quasar (hereafter N-loud quasar).

Baldwin et al. (2003, ApJ, 583, 649) claimed that the unusual nitrogen emission is likely due to high BLR metallicity; the metallicity measured from line flux ratios involving nitrogen is ~ 15 times the solar abundance. However, such extremely high metallicity is very hard to be reconciled with galaxy chemical evolutionary models. Then, we suspect that N-loud quasar is in especially high accretion phase with the nitrogen-rich gas clouds, not metal-rich gas clouds.

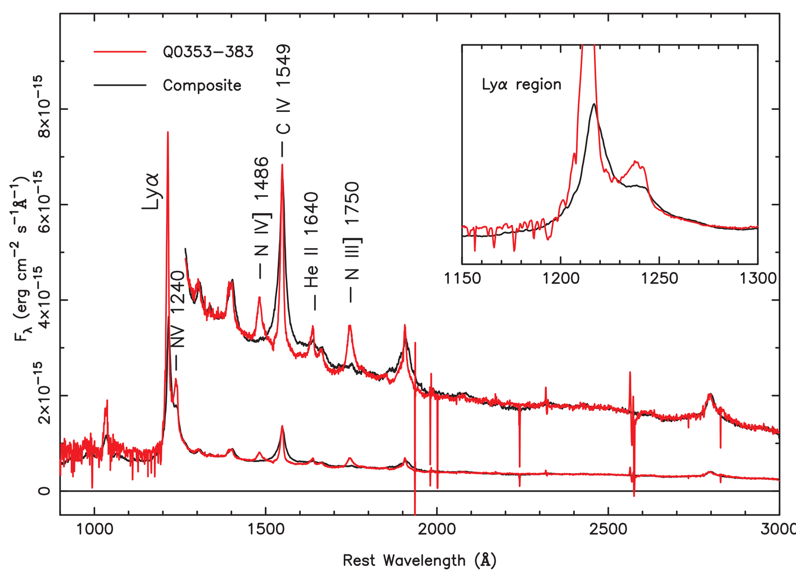

Fig. 4: Typical spectrum of nitrogen-loud quasar (red lines) and composite spectrum of normal quasars as nitrogen-quiet quasars (black lines), referring Baldwin et al. (2003, ApJ,583, 649).

N-loud quasar is not extremely metal rich

Recently, in order to examine whether the N-loud quasars have really extremely high metallicity, we investigated the NLR metallicity of N-loud quasars by using [OIII]λ5007 emission line; if the narrow-line region (NLR) metallicity is low, [OIII]λ5007 line should be very week due to the low equilibrium temperature of the ionized gas owing to significant metal cooling (Fig. 5). Then we found that the [OIII]λ5007 emission of N-loud quasars is quite strong (Fig. 6), suggesting that the NLR in N-loud quasars is not extremely metal rich at all (see also Araki et al. 2012, A&A, 543, 143).

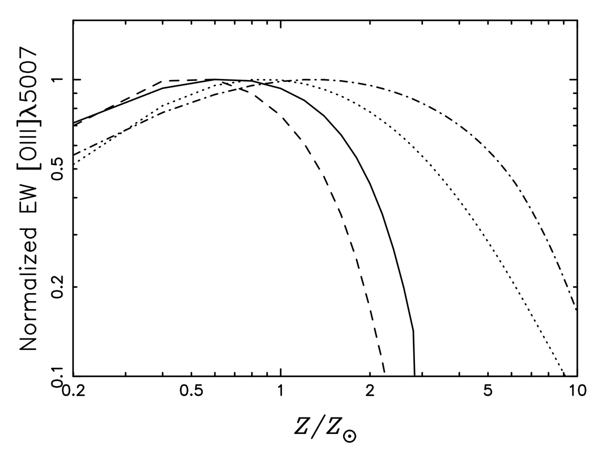

Fig. 5: Predicted equivalent width of [OIII]λ5007, as a function of $Z_{\rm NLR}$. Solid, dashed, dot-dashed, and dotted lines denote the models with (log $n_{\rm H}$, log U) = (1, -1.5), (1, -3.5), (4, -1.5), and (4, -3.5), respectively. The EW predictions are normalized by their peak values.

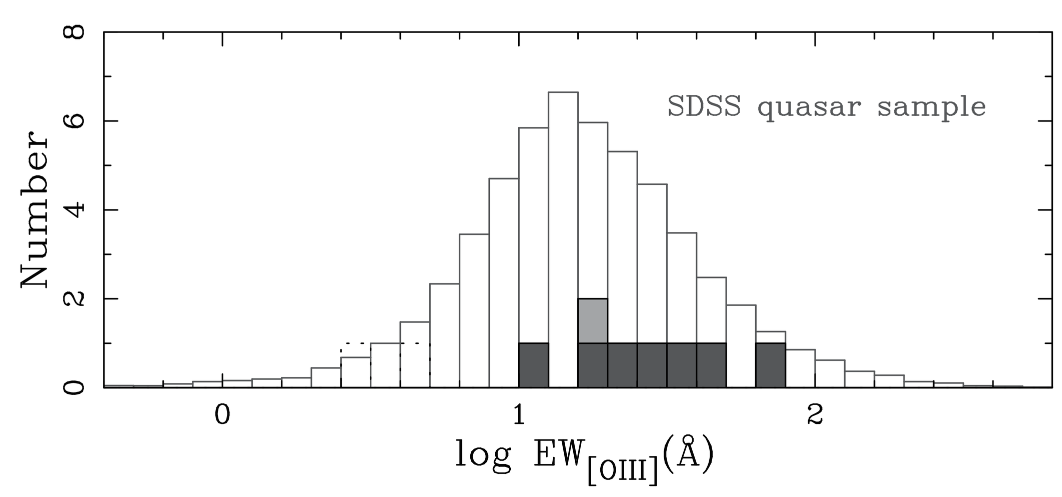

Fig. 6: The distribution of equivalent width of [OIII]λ5007. The filled histograms denote our sample of N-loud quasars (light gray for SDSS J1707+6443; Araki et al. 2012). The dotted histogram shows upper limited targets. The open histogram shows the distribution of normal SDSS quasars (Matsuoka et al. inprep.).

N-loud quasars in the AGN active phase

From N-loud quasar sample in Jiang et al. (2008, ApJ, 679, 962) we extracted N-loud quasars at $2.3 < z < 3.0$ that are already measured black hole mass in Shen et al. (2008, ApJ, 680, 169). Figure 7 shows the Eddington ratio distribution of N-loud quasars. We found that the Eddington ratio of N-loud quasars are significantly higher than the average of "normal" SDSS quasars, suggesting N-loud quasars in the AGN active phase.

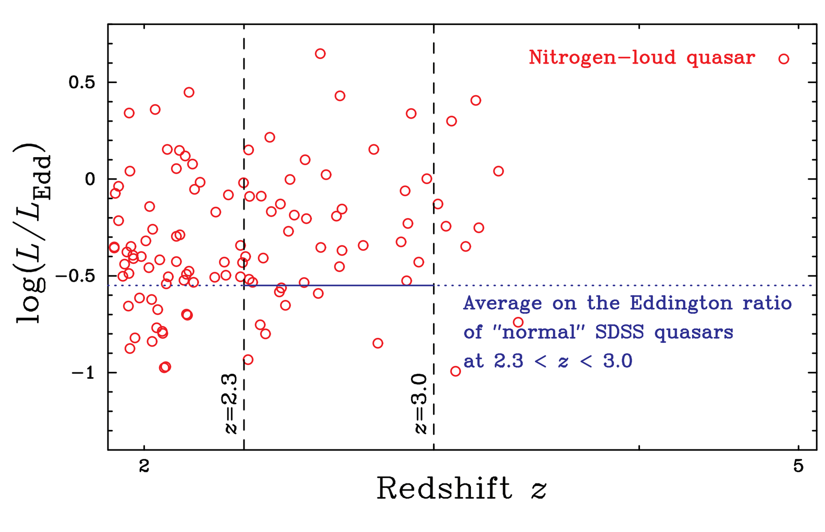

Fig. 7: The redshift distribution in the Eddington ratio of N-loud quasars. The horizontal line shows the average on the Eddington ratio of SDSS quasars (normal quasars). The Eddington ratio of N-loud quasars in the redshift range $2.3 < z < 3.0$ are higher than those of normal quasars.

4. AGN-starburst connection of low-luminosity quasars

Quasars we have observed in high-*z* universe through SDSS are only luminous quasars at each epoch, which may be well-matured populations (see Juarez et al. 2009; Kawakatu et al. 2003). In order to really understand the AGN-starburst connection, we have to focus on quasars with lower luminosity than SDSS quasars. In other words, we should investigate chemical properties in the wide Eddington-ratio range extending to low Eddington ratio, and the relation between the mass accretion and metals, i.e., the star formation for each accretion phase. Such less-luminous quasars should be explored with the HSC survey. It is crucial to investigate the AGN-starburst connection of HSC-selected quasars (i.e., low-luminosity quasars) in order to understand the coevolution of galaxies and SMBHs.