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Formation of SMBHs and QSO evolution

Nozomu Kawakatu [a,*], Naohisa Anabuki [b], Tohru Nagao [c], Masayuki Umemura [d], Takao Nakagawa [e], Masao Mori [f]

[a] SISSA, via Beirut, 34014 Trieste, Italy
[b] Department of Earth and Space Science, Graduate School of Science, Osaka University, 1-1 Machikaneyama, Toyonaka, 560-0043 Osaka, Japan
[c] Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi, 5, 50125 Firenze, Italy
[d] Center for Computational Sciences, University of Tsukuba, Ten-nodai, 1-1-1, Ibaraki 305-8577, Japan
[e] Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, JAXA, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
[f] Department of Law, Senshu University, Tama-Ku, Kawasaki 214-8580, Japan

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Abstract

The formation and growth of supermassive black holes (SMBHs) physically linked with bulges are considered. We focus on the radiation hydrodynamic process for the growth of SMBH in the optically thick starburst phase, where radiation from bulge stars drives the mass accretion on to a galactic center through radiation drag effect. In the present scenario, the AGN luminosity-dominant phase (QSO phase) is preceded by the host luminosity-dominant phase, which is called "proto-QSO phase". Comparing with observations, we found that the ultraluminous infrared galaxies that contain a type I Seyfert nucleus (a type I ULIRG) are the early phase of BH growth, namely correspond to the proto-QSO phase.

Keywords: Galaxies: active; Galaxies: bulges; Galaxies: formation; Galaxies: starburst; Quasars: general; Black hole

Contents

1. Introduction

The paradigm that ULIRGs evolve into QSOs was proposed by pioneering studies by Sanders et al. (1988) and Norman and Scoville (1988). Recently, Veilleux et al. (1999) have shown that the percentage of AGNs is 30–50% for ULIRGs. On the other hand, recent high-resolution observations of galactic centers have revealed that the estimated mass of a central "massive dark object"(MDO), which is the nomenclature for a supermassive BH candidate, does correlate with the mass of a galactic bulge; the mass ratio of the BH to the bulge is 0.002 as a median value (e.g., Kormendy and Richstone, 1995; Marconi and Hunt, 2003). In addition, it has been found that QSO host galaxies are mostly luminous and well-evolved early-type galaxies (e.g., McLure et al., 2000). Comprehensively judging from all these

* Corresponding author.
E-mail address: kawakatu@sissa.it (N. Kawakatu).

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findings, it is likely that ULIRGs, QSOs, Bulges, and SMBHs are physically related to each other.

2. A coevolution scheme for SMBHs and galactic bulges

Recently, Kawakatu et al. (2003) (hear after KUM03) have constructed a physical model for a coevolution of a QSO BH and an early-type host galaxy. This model is based on the radiation drag (see Umemura, 2001; Kawakatu and Umemura, 2002) incorporating the realistic chemical evolution which reproduces the color–magnitude relation of present-day bulge. In this model, we used an evolutionary spectral synthesis code 'PEGASE' (Fioc and Rocca-Volmerrange, 1997), in order to treat the realistic chemical evolution of the galactic bulges. According to the results of KUM03, after a galactic wind epoch $t_{\rm w}$, the bolometric luminosity is shifted from the host-dominant phase to the AGN-dominant phase (the QSO phase) at the transition time $t_{\rm crit}$. The former phase ($t_{\rm w} < t < t_{\rm crit}$) corresponds to the early stage of a growing BH because the mass accretion rate during this phase is so high that the mass growth of BH is significant. They defined this phase as a "proto-QSO". The proto-QSO phase is proceeded by an optically thick phase before the galactic wind, which would correspond to a ULIRG. In this phase, they predicted that the BH is much smaller than the QSO phase. After the AGN luminosity exhibits a peak at $t_{\rm cross}$, it fades out abruptly because almost all of the matter around BH has fallen onto the central BH. The fading nucleus could be a low luminosity AGN (LLAGN). However, a proto-QSO has not been identified to clarify which objects correspond to proto-QSOs.

3. Are type I ULIRGs missing link between ULIRGs and QSOs ?

Recently, Kawakatu et al. (2006) examined the BH-to-bulge mass relation among ULIRGs, QSOs and elliptical galaxies. Fig. 1 plots the R-band absolute magnitude of bulge components (spheroidal components), $M_{\rm R}$ (bulge) [mag], versus the black hole mass, $M_{\rm BH}$ [$M_\odot$] for 8 type I ULIRGs, 29 QSOs and 20 elliptical galaxies. In this work, we refer the type I ULIRGs as the ULIRGs that contain a type I Seyfert nucleus. In this figure, the red circles represent type I ULIRGs, the blue squares show QSOs, and the green circles denote elliptical galaxies. As seen in Fig. 1, we have found that type I ULIRGs have systematically smaller BH mass than QSOs and elliptical galaxies in spite of the comparable bulge luminosity because of the visual extinction $A_{\rm v} \approx O(1)$ (see Kawakatu et al., 2006 for details). In order to understand the physical relation between type I ULIRGs, QSOs and elliptical galaxies, we will compare above results with the results of KUM03 model. By using the KUM03 model, we predict the evolution of $M_{\rm R}$ (bulge) and $M_{\rm BH}$ for the different masses of bulges in Fig. 1. Here, we calculate the evolutional tracks in the $M_{\rm R}$–$M_{\rm BH}$ diagram for 4 different masses of bulges

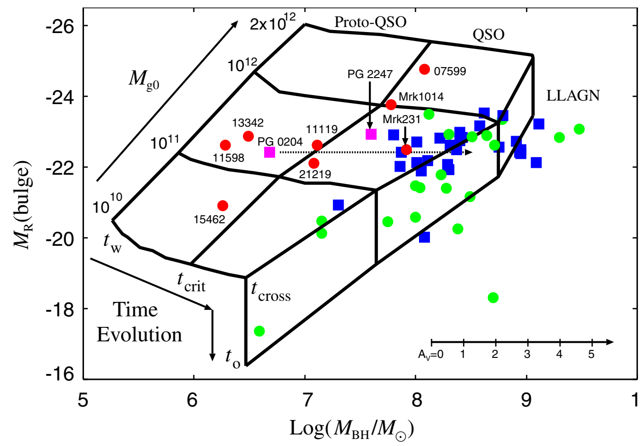

Fig. 1. Absolute R-band bulge magnitude versus the black hole mass for 8 type I ULIRGs (red circles), 27 QSOs (blue squares), 2 "unusual" QSOs (magenta squares) and 20 elliptical galaxies (green circles). The dashed arrow denotes the BH mass if we use the broad line width with 8000 km/s. The black horizontal arrow shows the optical extinction for the BLR of type I ULIRGs. The grids represent the prediction based on the radiation drag model for different mass of bulges ($M_{\rm g0} = 10^{10}$, 10^{11}, 10^{12}, and $2\times10^{12} M_\odot$), where $M_{\rm g0}$ is the initial gas mass in galactic bulges. Each evolutions shift from left (smaller BH) to right (larger BH) in this figure. $t_{\rm w}$ is the galactic wind time scale. $t_{\rm crit}$ is the time when the luminosity of bulges is equal to that of AGNs. $t_{\rm cross}$ is defined as the time when almost all of the matter around BH has fallen onto the central BH. t_0 denotes the final stage of the galaxy evolution. The host luminosity dominant phase (proto-QSOs) correspond to the region ($t_{\rm w} < t < t_{\rm crit}$). The AGN luminosity dominant phase (QSOs) correspond to the area ($t_{\rm crit} < t < t_{\rm cross}$). We call the phase ($t_{\rm cross} < t < t_0$) a low luminosity AGN (LLAGN). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

($M_{\rm g0} = 10^{10}$, 10^{11}, 10^{12}, and 2×10^{12} $M_\odot$), where $M_{\rm g0}$ is the initial gas mass in the galactic bulges. Here, we assume a Salpeter-type initial mass function (IMF) to be $\phi = {\rm d}n/{\rm dlog}\ m_* = A(m_*/M_\odot)^{-1.35}$ for a mass range of $[0.1M_\odot, 60M_\odot]$. The star formation rate (SFR) per unit mass at time t, $C(t)$, is assumed to be proportional to the gas mass fraction $f_{\rm g}$, $C(t) = kf_{\rm g}$ at $t < t_{\rm w}$ and at $t \geqslant t_{\rm w}$ $C(t) = 0$, where k is the constant rate coefficient. The evolutions of different masses of bulges proceed from left (smaller BH) to right (larger BH) in Fig. 1. As seen in Fig. 1, most type I ULIRGs are located near the proto-QSO phase. It would indicate that type I ULIRGs are the early phase of BH growth within younger bulge and then they evolve into QSOs. Namely, it would suggest that type I ULIRGs are the missing link between ULIRGs and QSOs. Also, our model can explain the difference from QSOs and elliptical galaxies as the evolution of host galaxies with nearly same BH mass. To sum up, we found that type I ULIRGs—QSOs—ellipticals would be explained by the monolithic evolution of the spheroidal systems.

4. Conclusions

Based on the radiation drag model for the BH growth, incorporating the chemical evolution of the early-type host galaxy, we have built up the coevolution model for a QSO

BH and the host galaxy. As a consequence, we have shown the possibility of the proto-QSO phase, which is optically thin and host luminosity-dominant, and has the lifetime comparable to the QSO phase timescale of a few 10^8 yr. The proto-QSO phase is preceded by an optically-thick ultraluminous infrared galaxy (ULIRG) phase. Moreover, comparing with observations, we found that type I ULIRGs are the early phase of BH growth, namely correspond to the proto-QSO phase. In summary, the present model could be a physical picture of evolution of ULIRGs to QSOs.

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