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Mergers and binary SMBH in the contexts of nuclear activity and galaxy evolution

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Abstract. Galaxy evolution and nuclear activity in galaxies can be connected with the cosmological evolution of super-massive black holes (SMBH) in the galactic nuclei. Galaxies are expected to merge frequently over the course of their formation and cosmological evolution, leading to the the formation of binary systems of SMBH. The dynamic evolution of binary SMBH may be a key factor affecting a large fraction of the observed properties of AGN and galaxy evolution. In this framework, different classes of AGN can be related in general to 4 different evolutionary stages in a binary SMBH: 1) early merger stage; 2) wide pair stage; 3) close pair stage; and 4) pre-coalescence stage.

Key words. active galactic nuclei – supermassive black holes – galaxy mergers

1. Introduction

Mergers are expected to occur frequently over the course of galaxy evolution. Formation of binary (or multiple) systems of SMBH is a likely outcome of galactic mergers. Binary black hole (BBH) systems should therefore play an important role in the nuclear activity in galaxies, since the latter is believed to be closely related to SMBH. Analytical work may help identifying main trends of the co-evolution of AGN and BBH. A good starting point for this work is provided by a number of studies of BBH dynamics (e.g., Begelman, Blandford & Rees 1984 and subsequent works) and interaction of supermassive black holes with nuclear environment in galaxies (Dokuchaev 1991; Polnarev & Rees 1994). Based on these studies, a scheme can be proposed that connects distinct stages of the binary evolution to characteristic types of AGN and galactic morphology associated with them.

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2. Merger stages and nuclear activity

1. Early merger. Individual galaxies or early mergers (while both BH retain their accretion disks). Timescale and magnitude of nuclear activity depend on the conditions in the central regions, and it is likely that cavity is formed around the BH, producing a "starving", low–power AGN (Dokuchaev 1991). If galaxies were formed at redshifts $z \sim 5 - 10$, the peak of single BH activity in galaxies is likely to occur at $z \sim 1$. Around this redshift, AGN with single SMBH may represent a (probably small) fraction of quasars and FR II type radio galaxies. At later epochs a single SMBH in the center of a galaxy is expected to reduce its fueling rate to $F \leq 10^{-3}$ [$\dot{\mathrm{M}}_{\mathrm{Edd}}$], and support a typical luminosity of $L \leq L_{\mathrm{Edd}}\, F \approx 10^{43} M_8$ erg/s. ($M_8 = M_{\mathrm{bh}}/10^8\, M_\odot$). This activity would be similar to that found in a typical Seyfert galaxy. The activity should remain weak during an early merger and relaxation of the galactic cores, which is expected to last for $\sim 10^8$ years (Polnarev & Rees 1994; Roos 1991). An AGN at this stage would have weak pc-scale and (FR I) kpc-scale jets, weak broad line regions, and very weak variability.

2. Wide pair. After the merger, the BHs sink toward the center of the stellar distribution and form a gravitationally bound system, with typical orbital separations $r_b \sim 1 - 10$ pc and initial orbital velocities $v_{init} \sim 10 - 100$ km/s. The dynamical friction would reduce the orbital separation to $r_b \sim 0.1 - 1$ pc, and the smaller BH would eventually lose its accretion disk. The accretion disk is aligned with the orbital plane and disrupted by the secondary BH. Interaction of the BBH with the stars and gas would increase the fueling rate by a factor of 10–100 (Dokuchaev 1991), bringing it close to $\dot{M}_{Edd}$ and supporting a luminosity of $\leq 10^{46}$ erg/s on timescales of $\sim 10^8$ years. BBH systems at this stage should produce strong pc-scale and (FR II) kpc-scale jets; strong broad line regions, and variability on timescales $\tau_{var} \sim 10^2$–10^4 days.

3. Close pair. At orbital separations $r_b \sim 10^{-2} - 1$ pc, the interaction of the secondary BH with the accretion disk intensifies so that it may even lead to a complete destruction of the disk. A turbulent activity in the nuclear region would result in strong thermal emission in the optical and high-energy band, varying on timescales $\tau_{var} \sim 10^0$–10^3 days. The jet production stops, and the level of radio emission is reduced substantially. The fueling rate is also reduced, and the resulting luminosities would reach up to $\leq 10^{45}$ erg/s. This stage lasts for $\leq 10^8$ years. An AGN at this stage is a "radio quiet" QSO (one should remember, however, that there are several possible factors potentially capable of quenching the jet production in AGN).

4. Pre-coalescence. At separations $r_b \leq 10^{-2}$ pc, gravitational radiation becomes the most important evolutionary factor. With $r_b \gg r_{acc}$, it is possible that an accretion disk is formed again around the BBH. Luminosities of up to $\leq 10^{45}$ erg/s should be expected. This stage would last for $\sim 10^7$ years. A typical AGN at this stage would be an intraday variable source (with prominent variability on timescales $\tau_{var} \sim 10^{-1}$–10^3 days), with "restarted" pc-scale radio jets, (and possible kpc-scale relics), and a prominent broad line region. The relativistic effects and orbital motion will result in variability on timescales that correspond to brightness temperatures of up to $\sim 10^{21}$ K (Lobanov 2004).

3. Conclusion

The proposed connection between BBH evolution and AGN is not necessarily unique and exclusive, but it should provide a viable skeleton for building up more complex and detailed models relating nuclear activity to the properties of multiple black holes in active galaxies. In particular, it would be important to investigate joint cosmological evolution of active galaxies and supermassive BBH embedded into their nuclei.

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