



MAX-PLANCK-GESELLSCHAFT



Binary supermassive black holes driving AGN activity

Introduction

Nuclear activity in galaxies believed to result from accretion onto supermassive black holes (SMBH) is a complex phenomenon regulated by a number of factors. It is widely recognized that the nuclear activity is also closely connected to galactic mergers. A merger has two most immediate effects on the environment of SMBH residing in the galactic nuclei. It perturbs substantially the dynamics of gas and stellar population in the merging galaxies, and it leads to formation of binary SMBH in the center of mass of the two galaxies merged.

The peak magnitude of the nuclear activity can be connected with the primary parameters of a supermassive SMBH system: the mass ratio and orbital separation of the two black holes. The description is based on two basic quantities:

the reduced mass
$$\tilde{M} = \frac{2M_2}{M_1 + M_2}$$

and reduced separation
$$\tilde{r} = 1 - \frac{r_\epsilon}{r + r_\epsilon}$$

of the two black holes in a binary system, where M_1 and M_2 are the masses of the two black holes, r is the actual separation

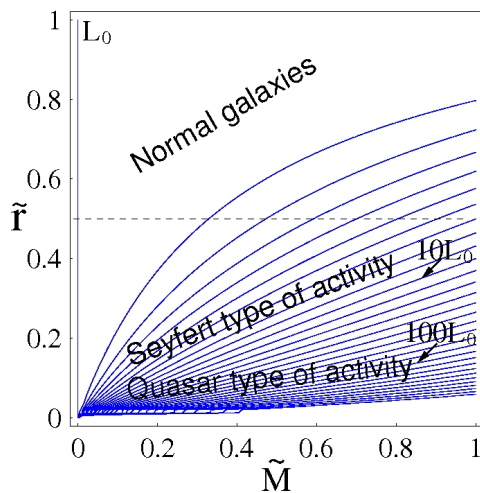
between the two black holes, and r_ϵ is the distance at which the two black holes become gravitationally bound.

The peak luminosity from an AGN can be crudely estimated from

$$L_{peak} = L_0 \left(1 + \frac{\tilde{M}}{2 - \tilde{M}} \frac{\tilde{M}}{\tilde{r}^2}\right)$$

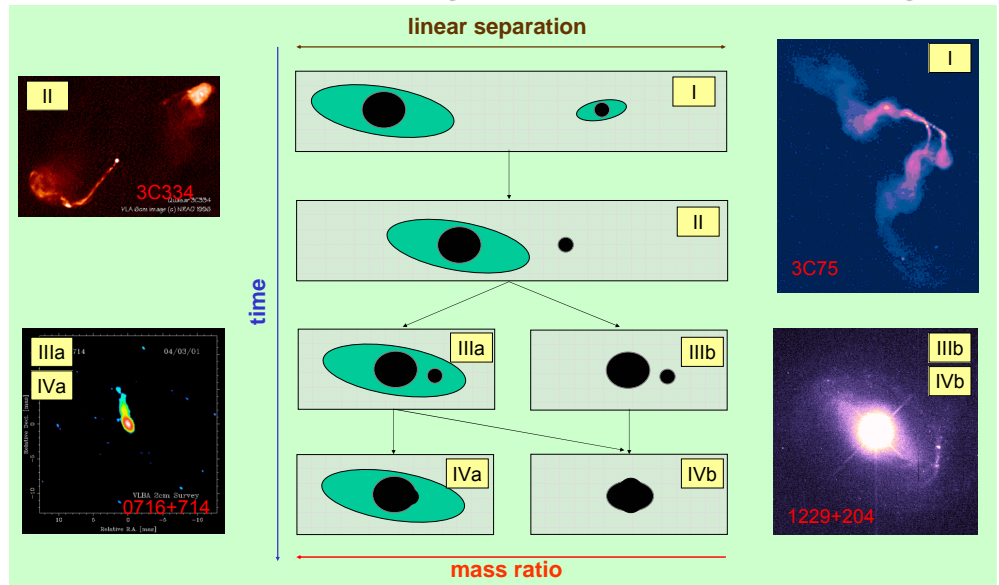
where L_0 is the luminosity of typical single, inactive galactic nuclei. This estimate predicts correctly the relative fractions of different types of active galactic nuclei (AGN) and explains the connection between the galactic type and the strength of the nuclear activity.

Binary SMBH and peak AGN luminosities



Peak luminosities of AGN calculated for a range of values of the reduced mass and binary separations in mergers and binary systems of SMBH in the centers of galaxies. Equal luminosity contours are drawn at a logarithmic step of 0.1, starting from a unit luminosity L_0 . The peak luminosity increases rapidly with increasing reduced mass and decreasing reduced separation, and it reaches $L_{peak} = 1000L_0$ for an equal mass binary SMBH at $\tilde{r} \approx 0.03r_\epsilon$. This would correspond most likely to powerful quasars residing in elliptical galaxies. At the same reduced separation, an unequal mass binary, with a reduced mass of 0.15, will only produce $L_{peak} = 10L_0$, which would correspond to a weak, Seyfert-type of active nucleus. This scheme predicts that about 70% of all galaxies should be classified as inactive, while the Seyfert-type of galaxies, with $L_{peak} = 10 - 100L_0$, should constitute 25% of the galaxy population, and the most powerful AGN, with $L_{peak} > 100L_0$, should take the remaining 5% of the galaxies.

Evolution of a binary SMBH and AGN activity



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 four different evolutionary stages in a binary SMBH: (I) early merger; (II) wide pair (soft binary); (III) close pair (hard binary); and (IV) pre-coalescence.
(I) Early merger. This stage corresponds to individual galaxies or early mergers (while both BH retain their accretion disks). Both SMBH in the are expected to have a significantly sub-Eddington luminosity. 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. Both nuclei would exhibit weak pc-scale and kpc-scale jets (FR I), weak broad line regions, and slow variability.
(II) Wide pair (Soft binary) The two SMBH form a gravitationally bound system, with typical orbital separations $r_b \sim 1-10$ pc and initial orbital. The dynamical friction reduces the orbital separation to $\sim 0.1-1$ pc, and the smaller BH would eventually lose its accretion disk. The remaining accretion disk is aligned with the orbital plane and disrupted by the secondary BH. Interaction of the BBH with the stars and gas would bring the fuelling rate and luminosity

close to the Eddington limit. BBH systems at this stage would produce strong pc-scale and kpc-scale jets (FR\,II); strong broad line regions, and variability on timescales of $\sim 102-104$ days.
(III) Close pair (Hard binary) At orbital separations of $\sim 10^{-2}-1$ pc, the interaction of the secondary BH with the accretion may 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 of $\sim 10-1000$ days. The fueling rate is also reduced, and the resulting luminosities would be somewhat below L_{Edd} . 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 radio emission production in AGN).
(IV) Pre-coalescence At separations $r_b \leq 10^{-2}$ pc, gravitational radiation becomes the most important evolutionary factor. At $r_b \ll r_{acc}$, an accretion disk is formed again around the BBH. A typical AGN at this stage would be an strongly variable object on timescales of $10^{-1}-10^3$ days, with "restarted" pc-scale radio jets, 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.

References:

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