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A Semi-Analytical Model of Quasar Formation† ⋆

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Abstract On the basis of Kang et al.'s semi-analytical model of galaxy formation and evolution, the joint formation and evolution of galaxies and their central massive black holes are studied. It is assumed that the activity of quasars is caused by merging of galaxies. Via the introduction of the mass accretion rate of black holes, the bolometric luminosity function of quasars with the redshifts in the region of $0 < z < 4.5$ is ascertained. With the respective limitations of the three factors, i.e., the Eddington ratio, black-hole mass function and two-point correlation function, the luminosity function predicted by the model may coincide with observations in the entire range of luminosity. This result reveals that the constant Eddington ratio cannot well describe the accretion of black holes, so the Eddington ratio has to be increased with the redshift in a certain range of redshift. The major merging of galaxies is the effective mechanism of triggering the quasar activity, while the minor merging can merely affect the quasars with low and intermediate luminosities. Its effect on the high-luminosity quasars is very small. At the place of z=1, the quasars with extremely high luminosities possess more intense properties of clustering than other quasars.

Key words: quasars: supermassive black holes—galaxies: evolution—methods: analytical

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1. INTRODUCTION

In recent years, along with the improvement of observational techniques, more and more quasars have been identified and the redshift has attained z=7.1[1]. The formation of these quasars has become a hot point of research in contemporary astrophysics. According to the current viewpoint, quasars are products of the violent activities of massive black holes. Via the accretion of the surrounding matter the masses of the black holes themselves increase. At the same time they emit energy outward. Hence the activities of quasars are triggered. As shown by observations, in the centers of almost all the massive galaxies there are massive black holes[2,3]. Black holes are concerned with many properties of the host galaxies, including the magnitudes and masses of galactic bulges, the velocity dispersion etc. They and the host galaxies influence each other and evolve together[4−7]. Therefore the research of the formation of quasars possesses important significance not only for understanding the formation and evolution of galaxies as well as the accretion of black holes, but also for providing clues for the study of the history of cosmic evolution as well as the large-scale structure of the universe.

The theory of hierarchical clustering of cold and dark matter (it is popular nowadays) can successfully interpret the formation and mass distribution of large-scale structures in the universe. In this framework the dark halos with small masses are formed at first. Then they combine together to form large and massive halos. On the other side, via the gas cooling, star formation and feedback, the barion matter forms galaxies in the centers of dark halos. The semi-analytical model of galaxy formation based on the theory of hierarchical structure of cold and dark matter has achieved a great progress and it has become an important tool for the study of galaxy formation and evolution. It may not only successfully predict galaxies' many properties which agree with observations, but also rather well foresee the history of star formation in the universe.

In the early period the semi-analytical model was used for research of quasars' luminosity function, space distribution, black-hole mass function etc.[8−10]. For the bolometric luminosity function, most part of researches only yielded the results of luminosity function but did not carry out restrictions from the two sides of the Eddington ratio and black-hole mass. Because the bolometric luminosity is the coupled result of the Eddington ratio and black-hole mass, the luminosity function which merely agrees with observations cannot justify the correctness of the model. Therefore it is very necessary to carry out a check of the model from the two sides of the Eddington ratio and black-hole mass. In this work it is assumed that the activity of quasars is caused by merging of galaxies. Under this hypothesis the semi-analytical model is used to determine the bolometric luminosity function of quasars with the redshifts in the region of $0 < z < 4.5$. The bolometric luminosity function is selected, because it may cover both the shielded and unshielded quasars, and this makes the sample to be more complete. However, because the bolometric correction is introduced, the statistical uncertainty is increased at the same time. We carry out analysis and examination of the model's results from the above-stated two sides. Finally we use the two-point correlation function to probe the properties of clustering of quasars. The bolometric luminosity function of quasars yielded by our best model may agree with observations in the entire ranges of redshift and luminosity.

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