Formation of Massive Black Holes in Globular Clusters

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The hydrodynamic formation of massive black holes (BHs) in globular clusters is studied. By incorporating the realistic chemical evolution of globular clusters into the radiation drag model, we scrutinize whether our scenario is successful.

§1. Introduction

The recent compilation of kinematical data concerning galactic centers in both active and inactive galaxies has shown that the mass of a central "massive dark object" (MDO), which is the term for a supermassive BH candidate, does correlate with the velocity dispersion of a galactic bulge.[8] This correlation suggests that the formation of a supermassive BH is physically connected with the formation of a galactic bulge. There remains the interesting question of whether this correlation holds for the mass scale of globular clusters. The low mass end of the BH hierarchy is suggested by recent observations of massive BHs in globular clusters, e.g., $M_{\rm BH} \approx 2 \times 10^4 M_\odot$ in G1[5] and $M_{\rm BH} \leq 2 \times 10^3 M_\odot$ in M15.[1),6)] However, the dynamical simulations of Baumgardt et al.[2] show that the mass of BH is less than $500-1000 M_\odot$ in G1. Also, it appears that the M33 nucleus does not have a massive BH with an upper limit of $1500 M_\odot$.[4] Thus, the question mentioned above is not answered. In this paper, on the basis of a radiation-hydrodynamic mechanism for the formation of massive BHs in globular clusters, we investigate whether the $M_{\rm BH}$-σ relation does hold in globular clusters.

§2. Model

First, we model the BH growth based on the radiation drag-driven mass accretion.[7),9)] Here, we assume a two-component system that consists of a spheroidal stellar cluster and inhomogeneous optically-thick interstellar medium (ISM) within it. In the radiation drag model, the mass of an MDO, $M_{\rm MDO}$, which is the total mass of a dusty ISM surrounding to the central massive object, is given by

$$M_{\rm MDO} = \eta_{\rm drag} \int_0^t \int_0^\infty \frac{L_{{\rm star},\nu}(t)}{c^2} \left(1 - e^{-\tau_\nu(t)}\right) d\nu dt, \qquad (2\cdot1)$$

where $L_{{\rm star},\nu}$ and τ_ν are the luminosity and optical depth of globular clusters. Here, we use $\eta_{\rm drag} = 0.34$.[7] In this model, we assume that an MDO of mass greater than $\sim 260 M_\odot$ undergoes direct collapse into a massive black hole. Thus, the BH mass estimated here represents the upper limit of a massive BH in a globular cluster.

Next, we construct the model for the chemical evolution of globular clusters. To

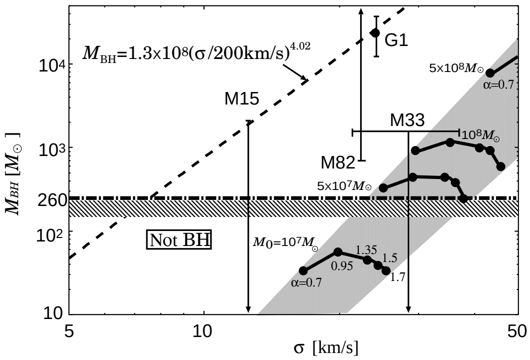

Fig. 1. Comparison between the theoretical prediction and the observational data regarding the BH mass for globular clusters. The ordinate is the mass of BH ($M_{\rm BH}$) in units of the solar mass, and the abscissa is the velocity dispersion of globular clusters (σ), in units of km/s. The shaded region represents the prediction of the present analysis. The observational data are plotted by symbols (M15, G1, M33 nucleus and M82). The dotted line represents the relation of Tremaine et al.[8]

treat the realistic chemical evolution, we use the evolutionary spectral synthesis code 'PEGASE'.[3] With thus, we can estimate the evolution of the physical properties of the globular clusters.

§3. BH mass-to-properties of globular clusters

By changing physical quantities (the slope, α, of the initial mass function, the timescale of starformation, $t_{\rm SF}$, and the initial mass of globular clusters, M_0), we reveal the relationship between the BH mass in globular cluster and its physical properties. As a result, we find that massive BHs with $10^{3-4}M_\odot$ can form if globular clusters satisfy the following conditions: (1) The slope of the initial mass function ($\phi = dn/d\log m_* \propto m_*^{-\alpha}$) is $\alpha \le 0.7 - 1.7$, where m_* is the stellar mass. (2) $t_{\rm SF}$ is almost equal to the typical age of intermediate mass stars, $2-8M_\odot \approx 10^{8-9}$ yr. (3) The stellar mass ($M_{\rm star,final}$) of globular clusters is more than a few $10^7 M_\odot$ at the present time. In addition, comparing our theoretical prediction (the shaded region in Fig. 1) with observational data, we find that typical globular clusters satisfying the above properties are not observed in Fig. 1. Hence, based on our model, it is unlikely for massive BHs to form in normal globular clusters. Moreover, the $M_{\rm BH}$-σ relation does not hold in such small spheroidal systems.

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