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ORIGINAL ARTICLE

Shaping the relation between the mass of supermassive black holes and the velocity dispersion of galactic bulges

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Abstract I use the fact that the radiation emitted by the accretion disk of supermassive black hole can heat up the surrounding gas in the protogalaxy to achieve hydrostatic equilibrium during the galaxy formation. The correlation between the black hole mass M_{BH} and velocity dispersion σ thus naturally arises. The result generally agrees with empirical fittings from observational data, even with $M_{BH} \leq 10^6 M_\odot$. This model provides a clear picture on how the properties of the galactic supermassive black holes are connected with the kinetic properties of the galactic bulges.

Keywords Galaxies · Galactic center · Supermassive blackholes · Velocity dispersion

1 Introduction

In the past decade, some observations have led to some tight relations between the central supermassive blackhole (SMBH) masses M_{BH} and velocity dispersions σ in the bulges of galaxies. These relations can be summarized as $\log(M_{BH}/M_\odot) = \beta \log(\sigma/200\ \mathrm{km\,s^{-1}}) + \alpha$. For $10^6 M_\odot \leq M_{BH} \leq 10^9 M_\odot$, the values of α and β have been estimated several times in the past 12 years: originally $(\alpha, \beta) = (8.08 \pm 0.08, 3.75 \pm 0.3)$ (Gebhardt et al. 2000) and $(0.14 \pm 1.3, 4.80 \pm 0.54)$ (Ferrarese and Merritt 2000), then $(8.13 \pm 0.06, 4.02 \pm 0.32)$ (Tremaine et al. 2002), and more recently $(8.28 \pm 0.05, 4.06 \pm 0.28)$ (Hu 2008), $(8.12 \pm 0.08, 4.24 \pm 0.41)$ (Gültekin et al. 2009), $(8.29 \pm 0.06, 5.12 \pm 0.36)$ (McConnell et al. 2011) and $(8.13 \pm 0.05, 5.13 \pm 0.34)$ (Graham et al. 2011). Generally speaking, empirical fittings show that $\alpha \approx 8$ and $\beta \approx 4$–5. These relations correspond to all morphological type galaxies. One can separate the fittings into different groups such as the early-type and late-type or elliptical and spiral. For example, McConnell et al. (2011) obtain $(\alpha, \beta) = (8.38, 4.53)$ and $(7.97, 4.58)$ for the early-type and late-type galaxies respectively if they are fitted separately. The slopes are shallower than the combined one ($\beta = 5.12$). Moreover, the slope β and the scatter of the M_{BH}–σ relation are still subject to debate, particularly at the low mass ends. Recently, Xiao et al. (2011) obtain a new M_{BH}–σ relation with low BH masses (below $2 \times 10^6 M_\odot$). They find a zero point $\alpha = 7.68 \pm 0.08$ and slope $\beta = 3.32 \pm 0.22$, which indicate β may be smaller for lower BH masses. Also, Wyithe (2006) obtained a better fit by using a log-quadratic form $\log(M_{BH}/M_\odot) = \alpha + \beta \log(\sigma/200\ \mathrm{km\,s^{-1}}) + \gamma'[\log(\sigma/200\ \mathrm{km\,s^{-1}})]^2$ with $\alpha = 8.05 \pm 0.06$, $\beta = 4.2 \pm 0.37$ and $\gamma' = 1.6 \pm 1.3$. Therefore, it is reasonable to doubt that the relation is not simply given by $M_{BH} \propto \sigma^\beta$ with β just a constant for all galaxies.

The M_{BH}–σ relation has been derived by recent theoretical models (Silk and Rees 1998; Adams et al. 2001; MacMillan and Henriksen 2002; Robertson et al. 2005; Murray et al. 2005; King 2005; McLaughlin et al. 2006; Power et al. 2011; Nayakshin et al. 2012). However, these models contain various assumptions and fail to explain the relations in the small SMBH mass regime ($\beta \approx 3.3$). In this article, I present a model to get an exact M_{BH}–σ relation, which can explain the parameters α and β in the empirical fitting in both small SMBH regime and apply to different types of galaxies. I use the fact that the strong radiation of the accretion disk of a SMBH can heat up the surrounding gas so that hydrostatic equilibrium of the latter is

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