Galactic Dynamics in the Era of Large Surveys
Proceedings IAU Symposium No. 353, 2019
M. Valluri & J. A. Sellwood, eds.

doi:10.1017/S1743921319009001

The demographics of central massive black holes in low-mass early-type galaxies

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Abstract. The existence intermediate mass black holes (IMBH, $M_{\rm BH} \lesssim 10^6 M_\odot$) at the centers low-mass galaxies with stellar masses between $(1-10)\times 10^9 M_\odot$ are key to constraining the origin of black hole (BH) seeds and understanding the physics deriving the co-evolution of central BHs and their host galaxies. However, finding and weighing IMBH is challenging. Here, we present the first observational evidence for such IMBHs at the centers of the five nearest early-type galaxies ($D < 3.5$ Mpc, ETGs) revealed by adaptive optics kinematics from Gemini and VLT and high-resolution HST spectroscopy. We find that all five galaxies appear to host IMBHs with four of the five having masses below 1 million $M_\odot$ and the lowest mass BH being only ∼7,000$M_\odot$. This work provides a first glimpse of the demographics of IMBHs in this galaxy mass range and at velocity dispersions <70 km/s, and thus provides an important extension to the bulge mass and galaxy dispersion scaling relations. The ubiquity of central BHs in these galaxies provides a unique constraint on BH seed formation scenarios, favoring a formation mechanism that produces an abundance of low-mass seed BHs.

Keywords. intermediate mass black holes, stellar dynamics, early-type galaxies.

1. Introduction

Intermediate mass black hole (IMBH) masses ($M_{\rm BH}$) scale tightly with host galaxy properties of massive ETGs, implying the growth of BHs and the overall growth of the host galaxies are closely linked. Yet, this scenario is not clear in the regime of low-mass galaxies because finding BHs in low-mass galaxies is extremely difficult. Little progress has been made over the past decade to characterize the population of lower mass BHs in low-mass galaxies including a fraction ($\lesssim$1%) of galaxies show which evidence for BHs via accretion signatures (Reines *et al.* 2013) and a handful of dynamical measurement using H_2 molecular gas (den Brok *et al.* 2015). These $M_{\rm BH}$ all fall below the MBH–galaxy properties scaling relation of the more massive galaxies up to 2 orders of magnitude. The cause of this change is still debated and may be tied to the formation history of the galaxy bulge (Kormendy & Bender 2012) or the star formation history of the entire galaxy (Terrazas *et al.* 2017).

2. Method

We developed a new technique to measure the spatial M/L variation in the nucleus of a galaxy to improve IMBH mass measurement. This spatial M/L variation is caused by the complexity of stellar populations and extinction.The first step is to obtain the *HST*/STIS spectroscopy to determine the stellar populations and M/L variations in the nucleus by fitting the spectroscopy to various single stellar populations (SSP) models. The color of the nucleus with the measured spatial M/L variability is then compared to the broad-band colors from *HST*/ imaging to create a color–M/L relation that describes

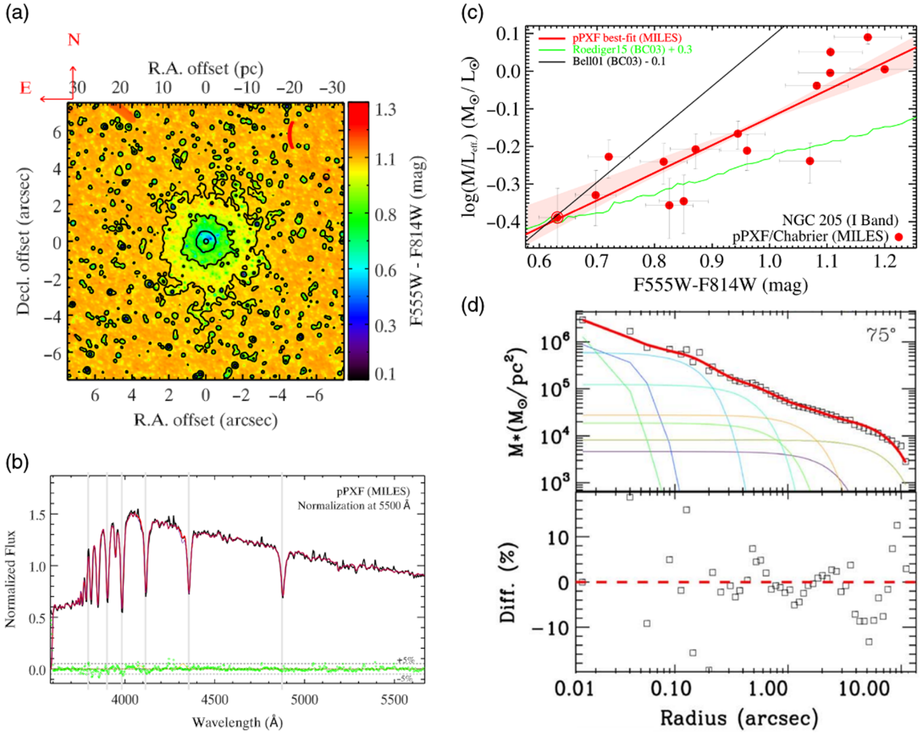

Figure 1. Panel (a): The nucleus color map of made from HST imaging and cross-convolved to match the point spread function (PSF). **Panel (b):** The central *HST*/STIS spectrum is shown in black, while the best-fitting stellar population synthesis model fit is shown in red. **Panel (c):** The effective mass-to-light ratio ($M/L_{\rm eff}$)-color relations. The horizontal axes show *HST* imaging color, while the vertical axes show $M/L_{\rm eff}$ determined from stellar population fits to STIS spectroscopy of their nuclei. **Panel (d):** comparison between the HST photometry data and their corresponding best-fit mass MGE models (red solid lines), which are the sum of multiple Gaussians (color thin lines). The fractional residuals (Data-Model)/Data are shown in the lower panels.

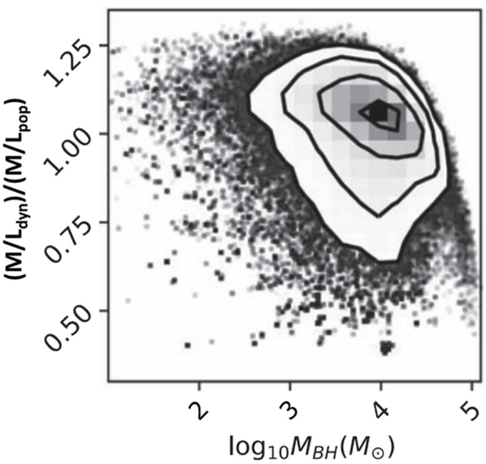

Figure 2. The χ^2 square distribution of the best-fit dynamical model using stellar kinematics and the mass model to determine the IMBH mass in the mass-scaling factor (M/L$_{d}ynn$)/(M/L$_{p}op$) and BH mass parameters space.

https://doi.org/10.1017/S1743921319009001 Published online by Cambridge University Press

the local stellar populations and dust. The color–M/L relation is the missing ingredient necessary to reduce uncertainty and obtain accurate IMBH mass from adaptive optics kinematics (see Fig. 1).

3. Results

Although our nearby ETGs sample has a limited volume and we may miss many ETGs distributed around many crowded environments such as Cen A. We find that all five galaxies appear to host central IMBHs with dynamical masses of $\lesssim 10^6 M_\odot$. The lowest mass among these IMBHs is in NGC 205, being only $\sim$7,000$M_\odot$ (see Fig. 2). Our work thus provides a first glimpse of the demographics of IMBHs in the galaxy mass range of $<10^{10} M_\odot$ and at velocity dispersions <70 km/s, and thus provides an important extension to the bulge mass and galaxy dispersion scaling relations. The ubiquity of central IMBHs in these galaxies (100%) provides a unique constraint on IMBH formation scenarios, favoring a formation mechanism that produces low-mass seed BHs from the death of the Pop. III stars.

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