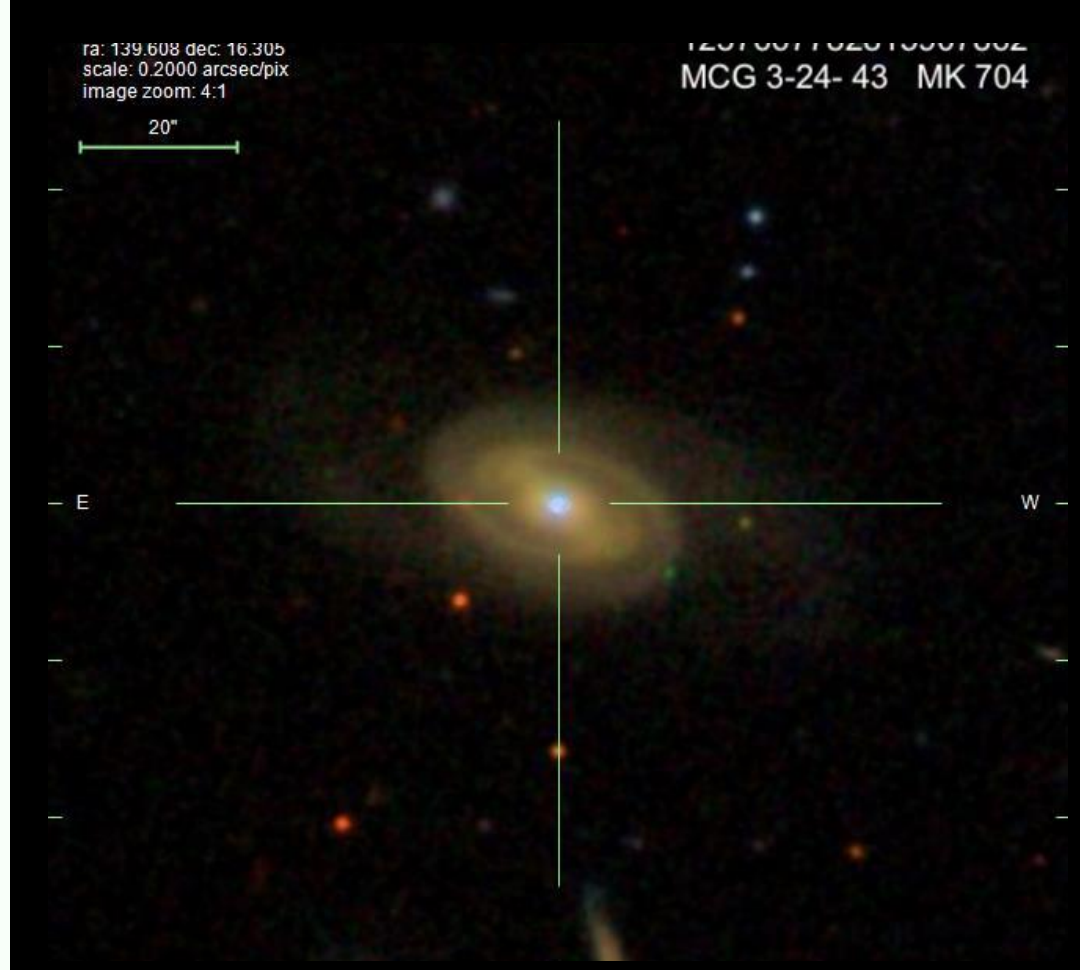

Merger Free Black Hole Growth and Co-evolution

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What Drives AGN Growth?

For AGN to grow, gas at kpc scales needs to lose momentum and flow to sub-pc scales to be accreted via some mechanism.

Torque exerted on gas during major-merger events can drive growth. However, disk-dominated galaxies, which have had merger free histories, require alternative explanations.

Minor mergers could have a similar affect while leaving little trace. Non-axisymmetric features (bars / spiral arms) could be a secular process funnelling gas into the centre, with studies such as Du et al. (2017) and Smethurst at al. (2019) supporting this.

Introduction:

There is substantial debate about the origins and drivers of the observed correlations between supermassive black holes (SMBHs) and their host galaxies such as the BH-galaxy mass relation. Major mergers, which drive the formation of dispersion-supported systems are often suggested.

However, the literature remains uncertain as to whether disk-dominated galaxies follow the stellar-BH mass relation. This would indicate co-evolution via secular processes. These differing studies have very different selection criteria for their active galactic nuclei (AGN) and their galaxies, thus may be sampling different parts of the population.

This study combines multiple past studies in order to seek a coherent picture of merger-free BH growth and co-evolution.

How Are AGN Modelled?

Simple AGN models typically assume accretion limited by the Eddington limit or by the availability of accretable gas.

The Eddington limit assumes spherical accretion which also releases radiation spherically. However, if AGN are growing via an accretion disk, super Eddington accretion may be achieved, though AGN are fundamentally limited by gas supply.

We consider whether the absolute SMBH growth rate (measured by the AGN luminosity) or the relative SMBH growth rate (measured by the Eddington fraction(EF)) is a better prediction of whether a merger free system is on the BH-galaxy relation.

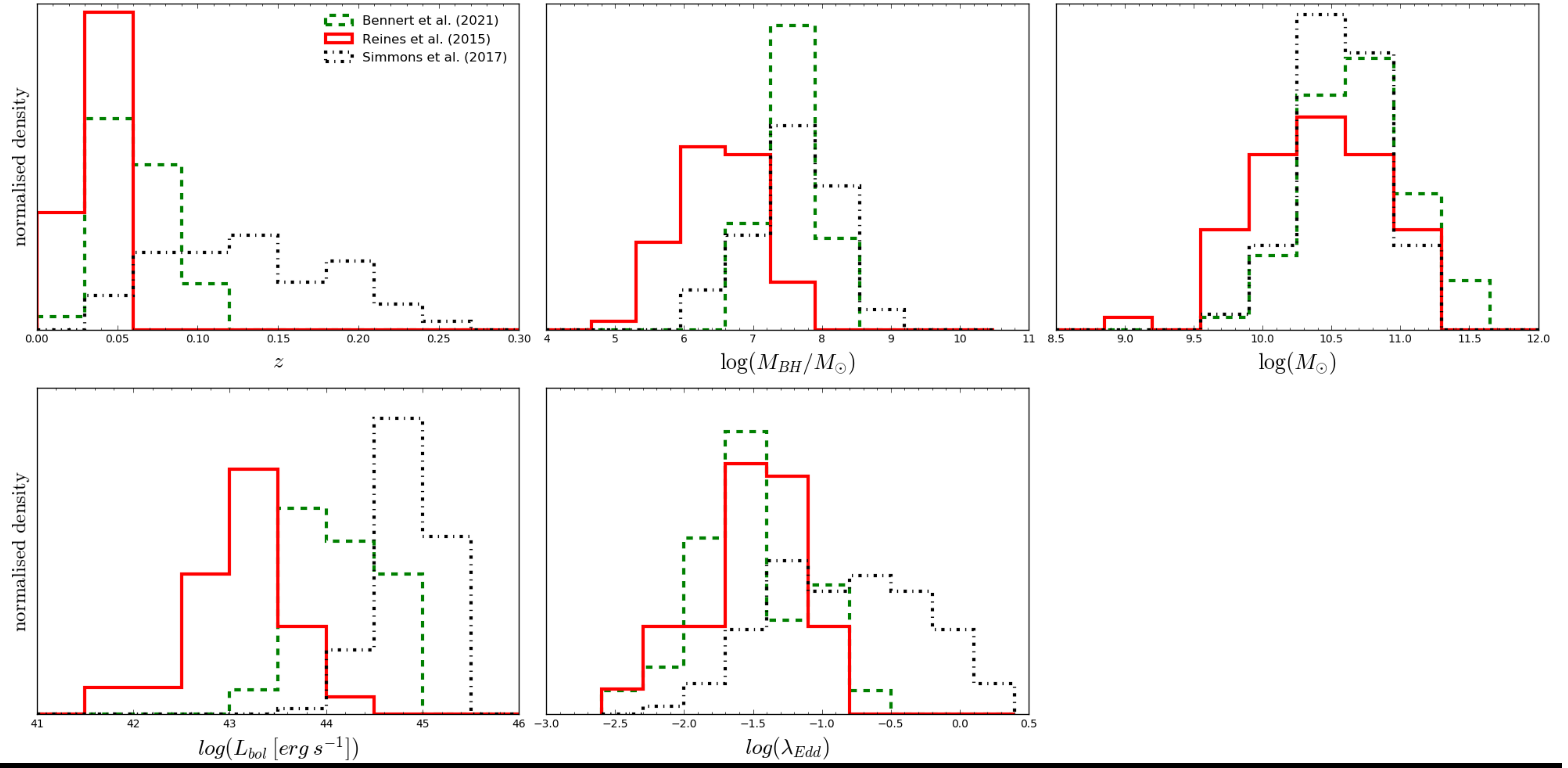


Figure 1: Normalised distributions for redshift, BH mass, galaxy mass, bolometric luminosity and EF. The red solid line represents the Reines et al (2015) (Rq15) sample with the green dashed line and the black dash-dot line representing the Bennert et al. (2021)(B21) and the Simmons et at (2017) (S17) respectively.

The three samples consist of disk-dominated galaxies hosting SMBH in the local universe. The S17 consists of 97 galaxies hosting highly luminous AGN selected from a multi-wavelength analysis by Edelson & Malkan (2012) and cross-matched to SDSS DR7. The R15 sample contains 62 moderate luminosity AGN selected from the NASA-Sloan Atlas (NSA), which contains a redshift cut of $z < 0.05$, using emission line cuts. The B21 contains 64 luminous AGN from SDSS DR6 and restricted to a redshift range of $0.02 < z < 0.1$ and a minimum black hole mass of 10^7 $M_\odot$.

Differences in redshift, luminosities, mass and volume of the samples show that they are sampling very different parts of the BH and galaxy luminosity functions. By analysing these samples in combination we mitigate some of these strong selection effects and can examine the entire population in order to draw general conclusions about SMBH growth in the merger free regime.

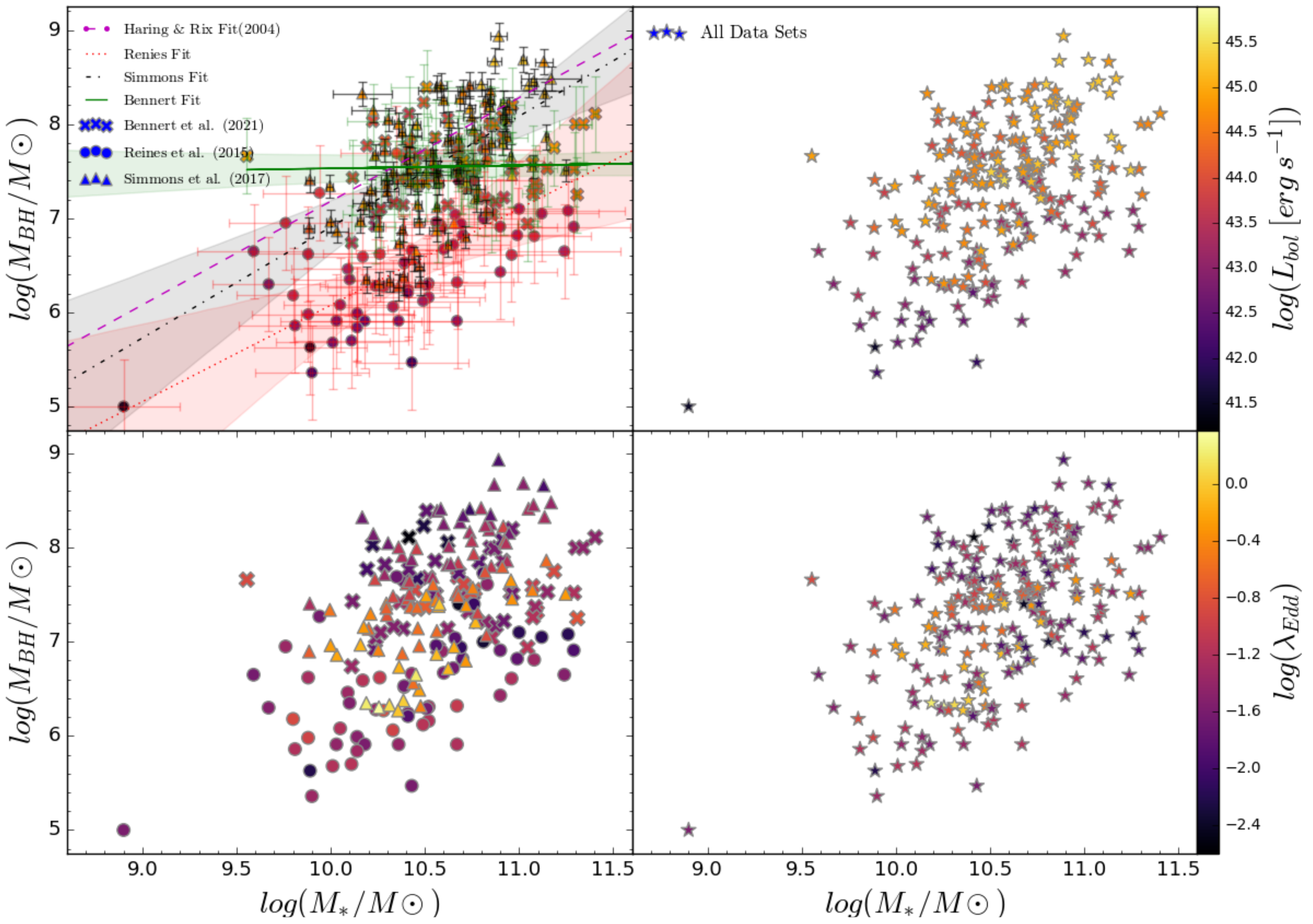


Figure 2. Black hole-Galaxy relation: Top Left: Red solid line and circles represents the R15, The green solid line and Xs representing B21 with the black dashed line and triangles representing S17. The pink dot-dashed line represents the Haring & Rix (2004) and the colour bar represents bolometric luminosity. Top Right: Same as top left, however, trend lines removed and individual sample shapes removed for clarity. Bottom Left: Same point shapes as Top Left but colour represents EF. Bottom Right: Same as Bottom Left but with individual sample shapes removed.

The Haring & Rix (2004) (HR) relation for elliptical galaxies is included in Figure 2 as a comparison. S17 sample relation is in striking agreement with HR while R15 falls largely below and B21 has a flat relation. The disparity with the relations may be due to the sampling methods. S17 selected highly luminous AGN, R15 sampled a smaller volume and B21 made cuts on minimum black hole mass.

Despite different selection methods of each sample, the combination appears to form a continuous overall sample. We also notice that the bolometric luminosity appears to be a better predictor of whether a system will be on the HR relation than the EF. Objects can populate all parts of this diagram with different EF. However, there is a clear trend in luminosity as the BH mass and stellar mass increase even across the three disparate samples. This could be because BHs with higher absolute accretion rates are more likely to be observed at higher BH masses, which would bring them closer to the co-evolution relation.

The BHs below the HR relation are growing at a range of Eddington fractions and luminosities. We would like to know whether these growth rates are consistent with typical AGN growth rates and duty cycles and thus whether these BHs may be in the process of growing on to the relation.

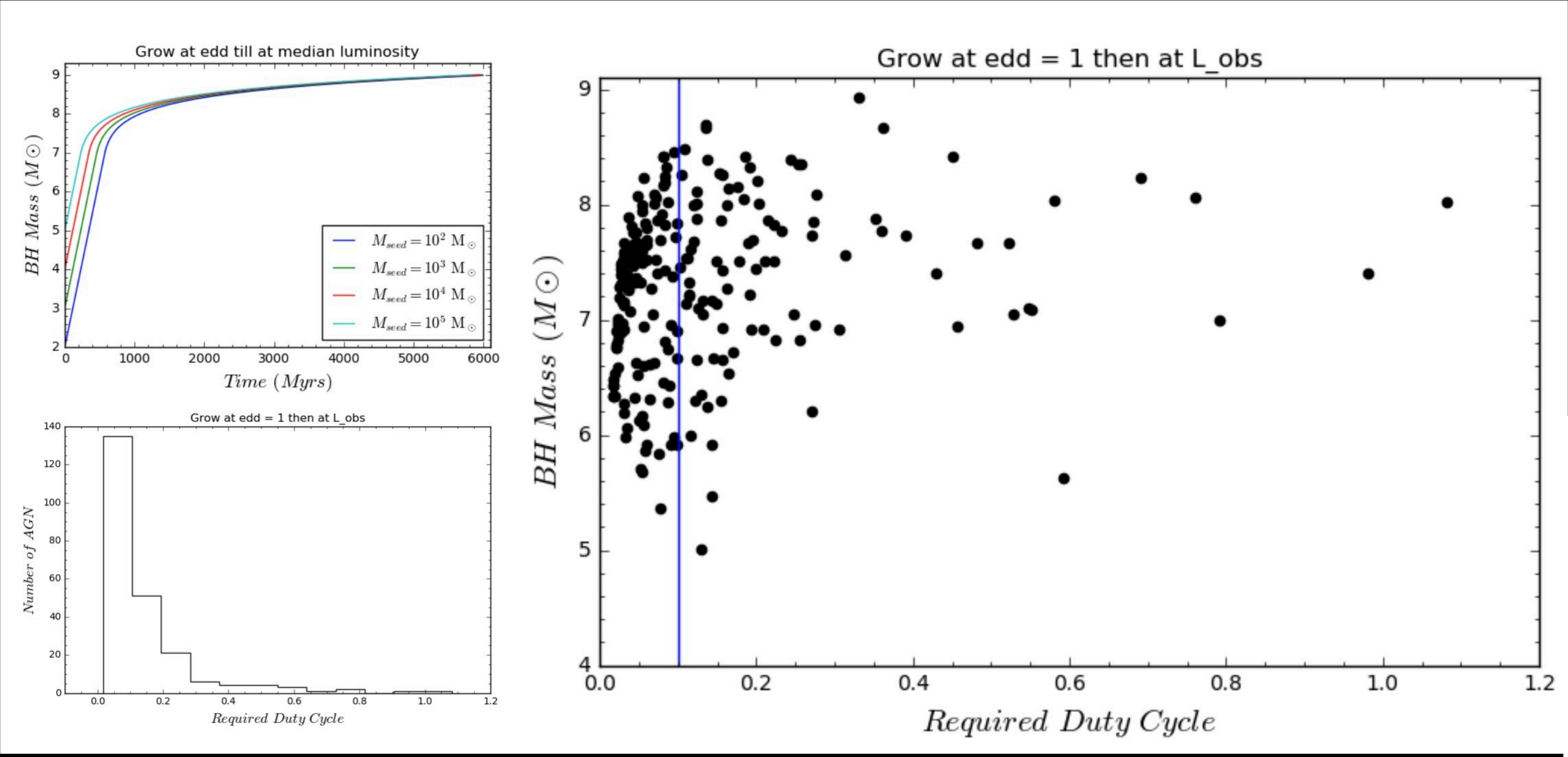
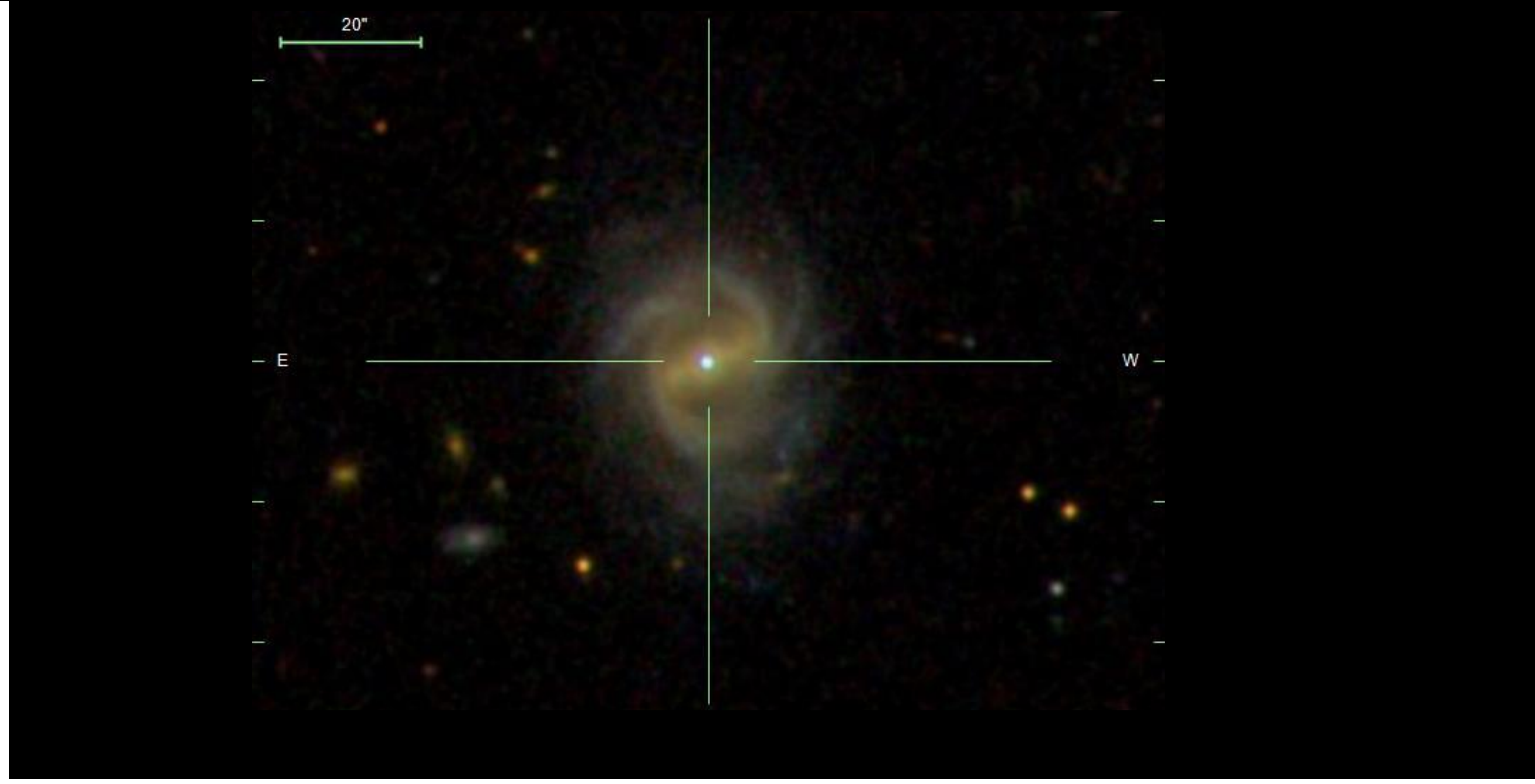


Figure 3: Top Left: The plot shows BH mass against accretion time for a variety of seed masses with dark blue, green, red and light blue representing 10^2,10^3,10^4 and 10^5 M ⊙ respectively. Bottom Left: A histogram of the required AGN duty cycles to reach the observed mass. Right: BH mass against required AGN duty cycles to reach the observed mass with the blue line representing the typically observed duty cycle

The first plot demonstrates that AGN have the ability to grow significantly in a relatively short timespan and that seed mass has little effect on the final mass. Therefore, it is reasonable to assume that some of these AGN may be in their first growth period.

In the model AGN grow at the Eddington rate until they reach their observed luminosity. We find that the majority of AGN reach their observed mass around a duty cycle of 0.1 fraction off life time AGN is highly accreting), which is the typically observed duty cycle for AGN. A number of AGN have infeasible duty cycles and some are > 1. The model assumes the AGN being observed are at a rate close to their maximum. However, studies such as Schawinski et al. (2015) suggest AGN luminosities flicker, this could be part of the reason some of the AGNs duty cycles are unrealistically long.



Conclusion

Initial analysis of three disparate samples of AGN hosted in disk-dominated galaxies shows bolometric luminosity, which traces absolute growth, is a good indicator to whether an AGN was growing on to the HR relation Our simple model indicated that these SMBH can grow on to the relation within a reasonable duty cycle, highlighting the importance of non-major merger driven growth.

Further work is being done to create a more detailed model which can simulate the growth of numerous AGN across the parameter space and sample to produce a coherent picture of AGN growth within disk-dominated galaxies.

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