Normal black holes in bulge-less galaxies: the largely quiescent, merger-free growth of black holes over cosmic time

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ABSTRACT

Understanding the processes that drive the formation of black holes (BHs) is a key topic in observational cosmology. While the observed $M_{\rm BH}$–$M_{\rm Bulge}$ correlation in bulge-dominated galaxies is thought to be produced by major mergers, the existence of a $M_{\rm BH}$–$M_{\star}$ relation, across all galaxy morphological types, suggests that BHs may be largely built by secular processes. Recent evidence that bulge-less galaxies, which are unlikely to have had significant mergers, are offset from the $M_{\rm BH}$–$M_{\rm Bulge}$ relation, but lie on the $M_{\rm BH}$–$M_{\star}$ relation, has strengthened this hypothesis. Nevertheless, the small size and heterogeneity of current datasets, coupled with the difficulty in measuring precise BH masses, makes it challenging to address this issue using empirical studies alone. Here, we use Horizon-AGN, a cosmological hydrodynamical simulation to probe the role of mergers in BH growth over cosmic time. We show that (1) as suggested by observations, simulated bulge-less galaxies lie offset from the main $M_{\rm BH}$–$M_{\rm Bulge}$ relation, but on the $M_{\rm BH}$–$M_{\star}$ relation, (2) the positions of galaxies on the $M_{\rm BH}$–$M_{\star}$ relation are not affected by their merger histories and (3) only ∼35 per cent of the BH mass in today's massive galaxies is directly attributable to merging – the majority (∼65 per cent) of BH growth, therefore, takes place gradually, via secular processes, over cosmic time.

Key words: methods: numerical – galaxies: interactions – galaxies: evolution – galaxies: supermassive black holes

1 INTRODUCTION

The co-evolution of galaxies and their black holes (BHs) is a central theme of our galaxy formation paradigm. In the nearby Universe, several correlations are observed between BH mass and the properties of the host galaxy, such as its velocity dispersion (Magorrian 2006). Simulations show that mergers (in particular 'major' mergers, i.e those with near-equal mass ratios) are efficient at building bulges (e.g. Toomre & Toomre 1972; Barnes 1992), although some bulges may form via other processes, such as disk instabilities (e.g. Dekel et al. 2009; Kaviraj et al. 2013a) and, in cases where gas

Задача – выяснить, какую роль играют mergings в формировании галактик и их SMBH?

- The correlation between BH and bulge mass is often considered to be a product of galaxy mergers. Combined with the fact that active galactic nuclei (AGN), and thus growing BHs, are often observed in systems undergoing major mergers, it is reasonable to suggest that this process could create the observed M_{BH}–M_{Bulge} correlation, by simultaneously building the BH and the galaxy bulge.
- **ОДНАКО:**

There is evidence that spiral galaxies with low central velocity dispersions, and therefore low bulge masses, tend to have overmassive BHs (Sarzi et al. 2002; Beifiori et al. 2009) when considering the MBH–MBulge correlation, which suggests that the processes that build the BH and the bulge may be different.

- Другая точка зрения: BHs may be largely built by secular processes. Этот вывод созвучен работе Lofthouse et al 2017: на пике SF (z~2) только 21% blue spheroids демонстрирует disturbed form.
- Here, we use Horizon-AGN, a cosmological hydrodynamical simulation (Dubois et al. 2014) to probe the role of mergers in BH growth over cosmic time. Simulation model has a dark matter mass resolution of 8×107 M, a stellar-mass resolution of 2×106 M and a spatial resolution of 1 kpc.

We note that BH growth is not prescriptively linked to mergers in the simulation. The growth in BH mass is simply a result of accretion from ambient gas, but will naturally respond to changes in the geometry and dynamics of the gas that is induced by a merger e.g. if major mergers efficiently funnel gas into the centre of a remnant then BH growth could be accelerated. However, the model is not set up to preferentially build BHs during mergers.

- Минимальная масса галактики log M = 8.5
- Задаётся начальная масса BH (50Mc).

However, BH masses quickly become self regulated, so that the exact choice of seed mass is not important. Рост массы – за счёт аккреции, но она ограничена эддингтоновским пределом, хотя массы могут продолжать рост за счёт слияния BH.

- Following their formation, each BH is able to grow through gas accretion, or through coalescence with another black hole. As galaxies grow, they expel or consume their supply of cold gas leading to reduced BH accretion rates.

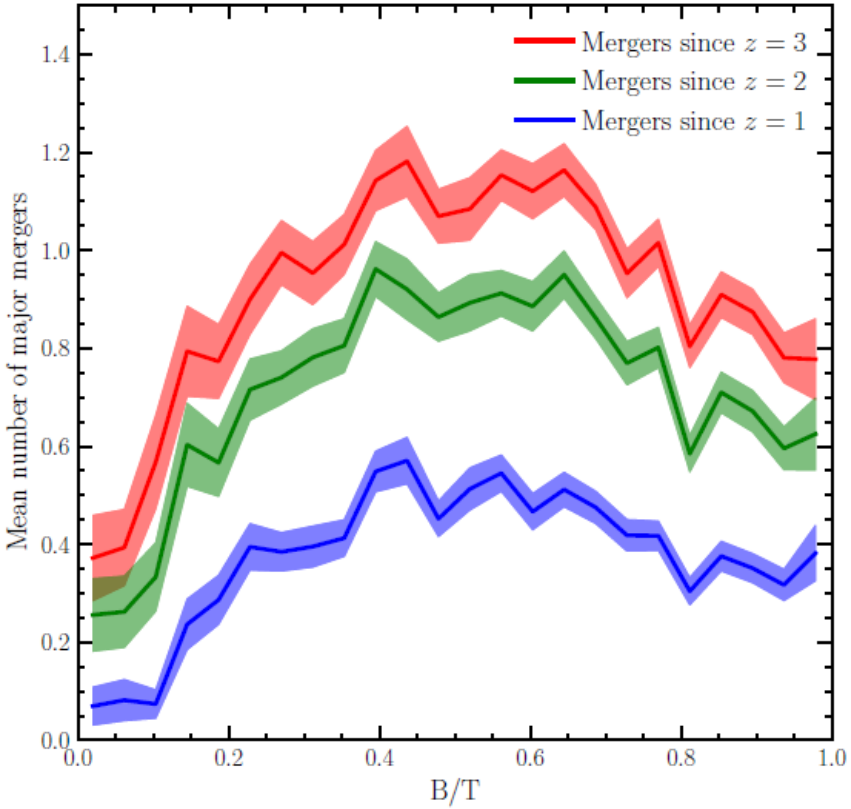


Figure 1. The mean number of major mergers that local massive galaxies ($M_\star > 10^{10.5}$ at $z = 0$) have undergone after a given redshift, as a function of their bulge to total stellar mass (B/T) ratios. The colour corresponding

- The probability that bulge-less galaxies (B/T < 0.1) have undergone any major mergers between z = 1 and the present day is essentially zero. However, around one in four and one in three of these galaxies have undergone a major merger since z=2 and z=3 respectively.

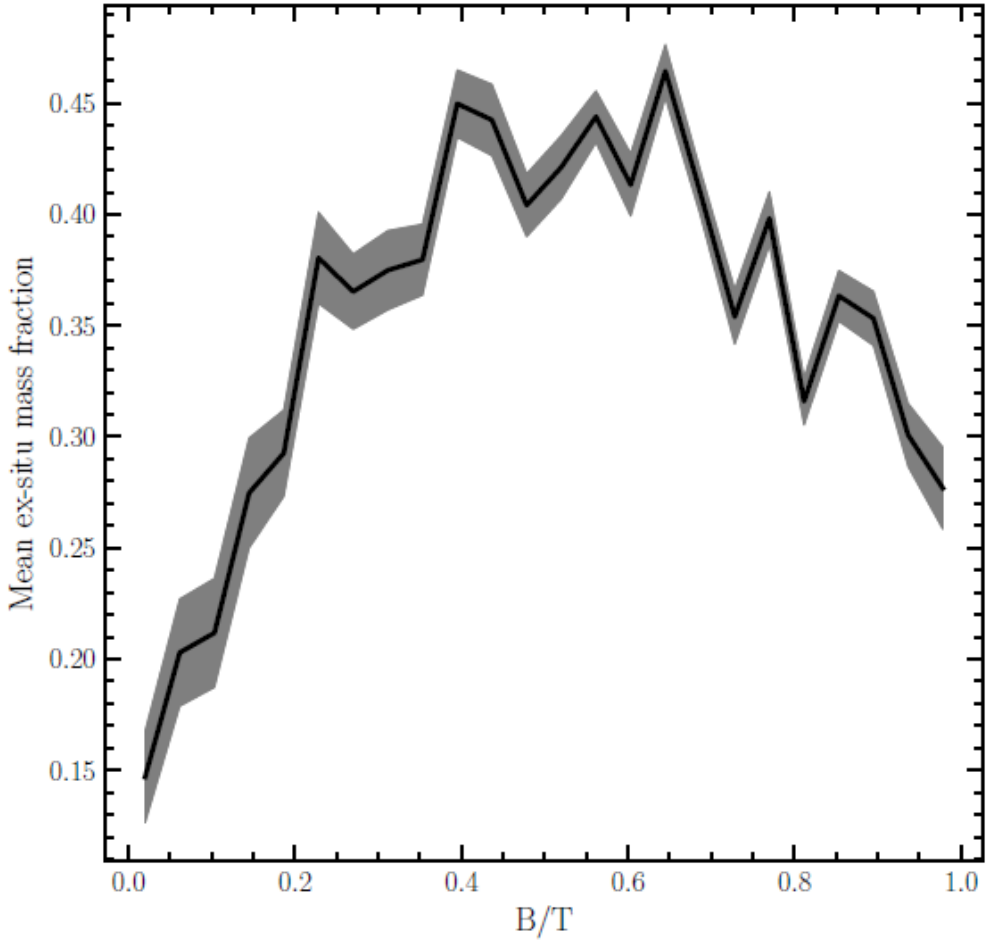
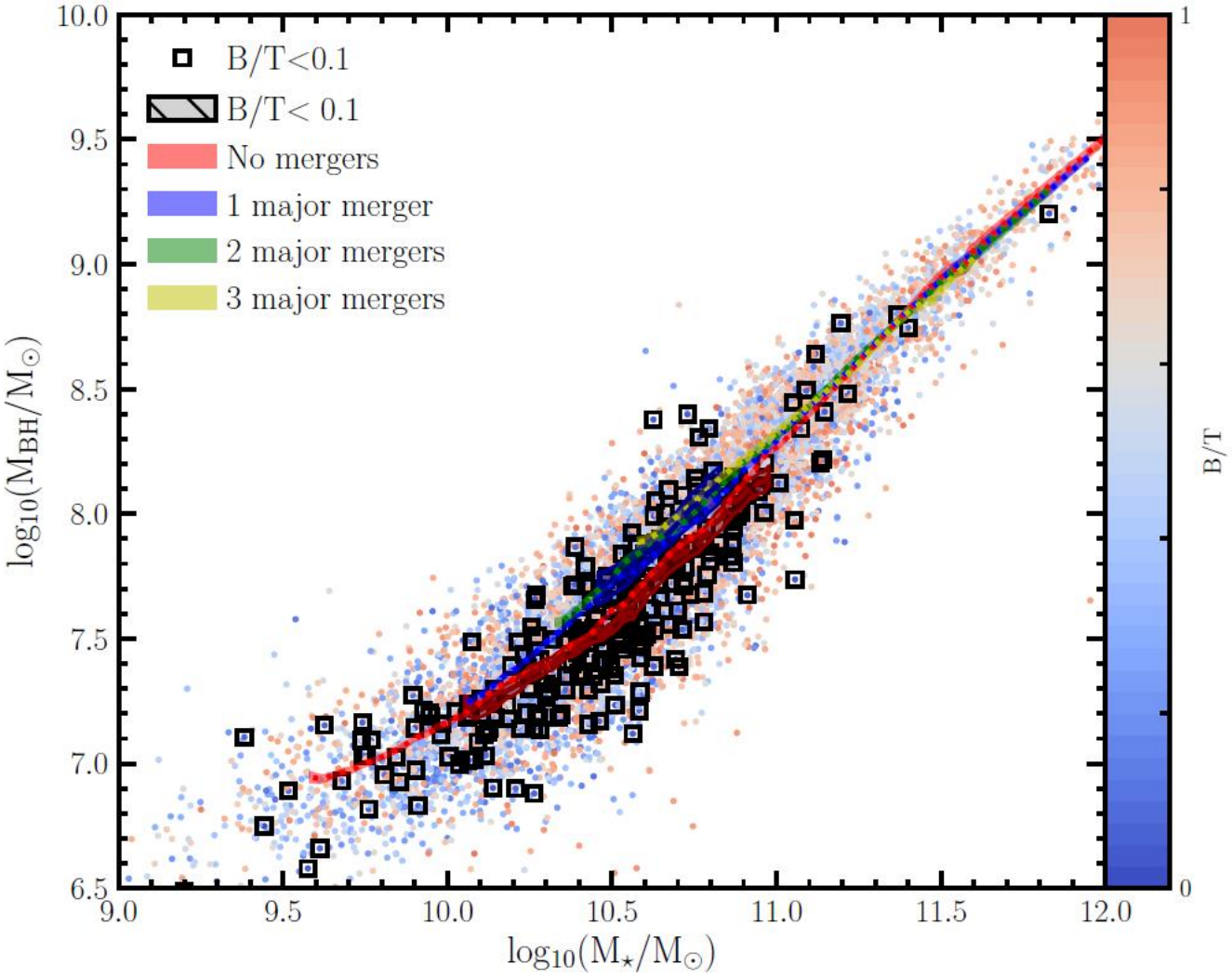


Figure 2. The mean fraction of ex-situ mass in today's massive galaxies ($M_\star > 10^{10.5}$ at $z = 0$), as a function of their B/T ratio. Galaxies with low B/T ratios are likely to have low ex-situ mass fractions, indicating that the majority of their stellar mass formed via secular processes.

Bulge-less galaxies host very low ex-situ mass fractions – less than 15 per cent, on average.


B/T<0.1
B/T< 0.1
No mergers
1 major merger
2 major mergers
3 major mergers
log10(MBH/M⊙)
log10(M⋆/M⊙)
B/T
10.0
9.5
9.0
8.5
8.0
7.5
7.0
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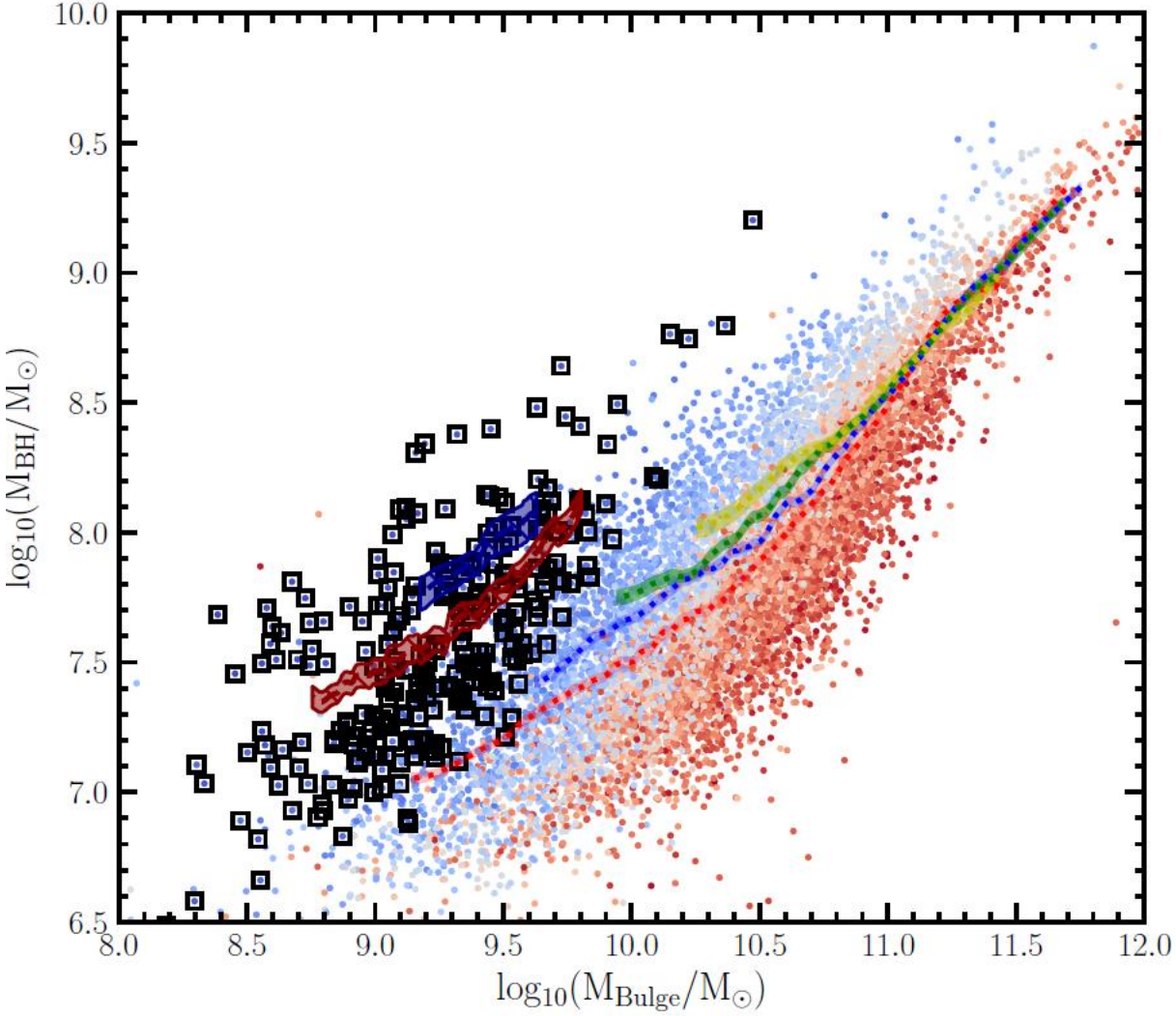
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log10(MBH/M⊙)
log10(MBulge/M⊙)

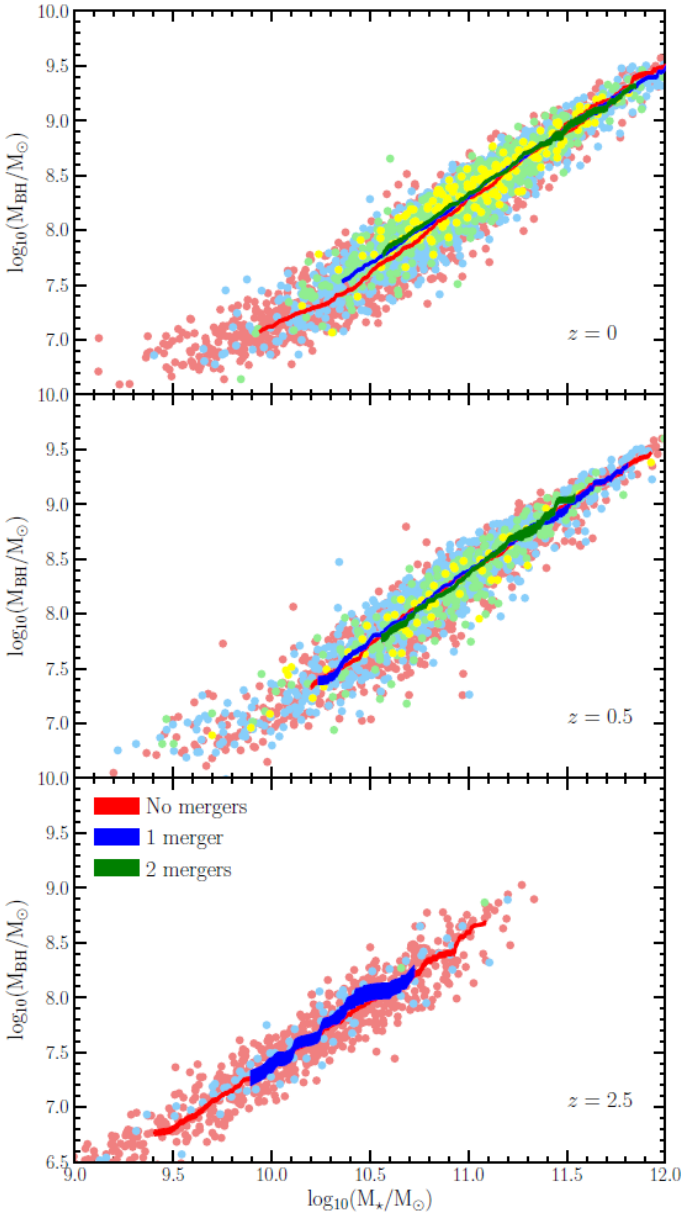

Figure 6. Evolution of the M_{BH}–$M_\star$ relation in Horizon-AGN for local massive galaxies. Solid coloured lines show a running mean for galaxies that have undergone 0 (red), 1 (blue) and 2 (green) major mergers before the redshift indicated in each panel, where the width of the line indicates the standard error on the mean.

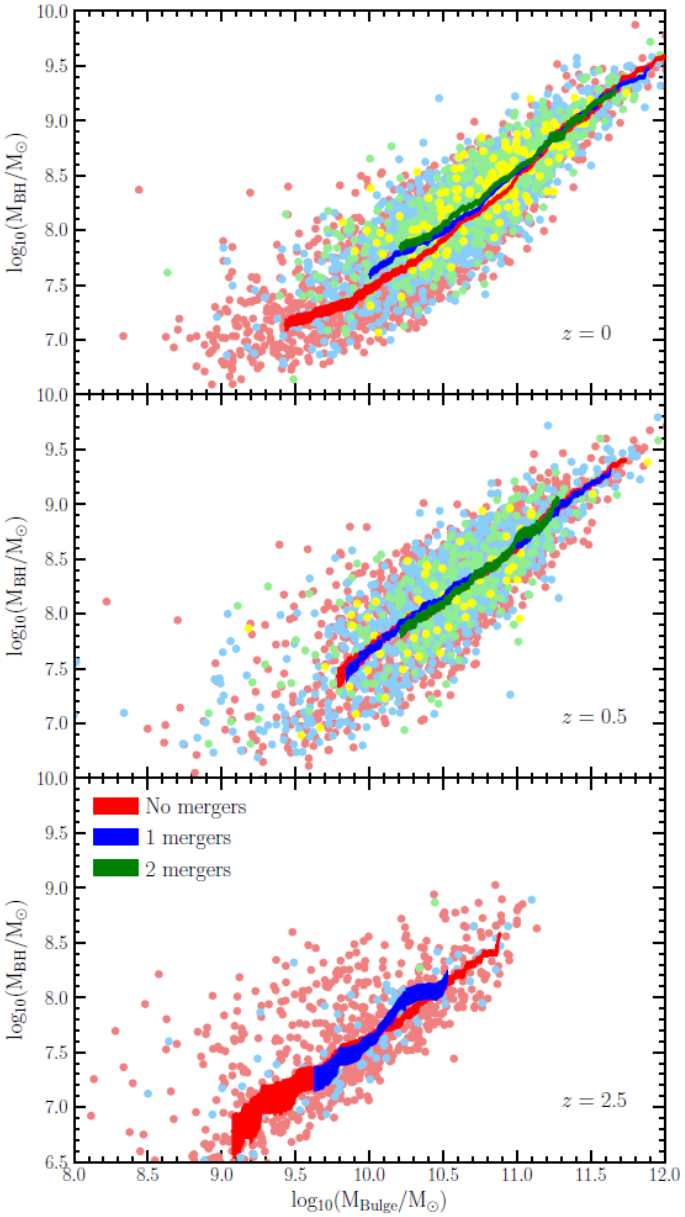

Figure 7. Evolution of the M_{BH}–M_{Bulge} relation in Horizon-AGN. As in Figure 6, solid coloured lines show a running mean for galaxies that have undergone 0 (red), 1 (blue) and 2 (green) major mergers before the redshift indicated in each panel, where the width of the line indicates the standard error on the mean.

SUMMARY

- Как теоретические работы, так и наблюдения показывают, что пик космического SF связан не со слиянием галактик, а с космологической аккрецией газа. А поскольку основная масса звёзд сформировалась именно в эту эпоху, основное количество существующих сейчас звёзд не имеет отношение к мержингам.
- Аналогичные результаты получены нами в отношении роста массы BHs: она зависит в меньшей степени от мержинга, в большей- от внутренних процессов, связанных со SF.

- Almost all bulge-less galaxies have undergone no major mergers since z = 1. However, 25 per cent of such systems have had a major merger since z = 3.
- The number of major or minor mergers that a galaxy has undergone does not alter a galaxy's position on the MBH–M* relation, indicating that mergers are not a significant mechanism for feeding the BH.
- Bulge-less galaxies lie offset from the MBH–MBulge relation observed in the general population. The offset of the bulge-less galaxies is driven by the fact that these galaxies have normal black holes but under-massive bulges (due to a smaller number of mergers).
- Only 35 per cent of the BH mass in galaxies more massive than 109.5M in today's Universe is directly attributable to mergers. 22 per cent is driven by major mergers and 13 per cent is driven by minor mergers. Secular processes, therefore, account for the creation of the majority (65 per cent) of BH mass over the lifetime of the Universe