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Two channels of growth of supermassive black holes*

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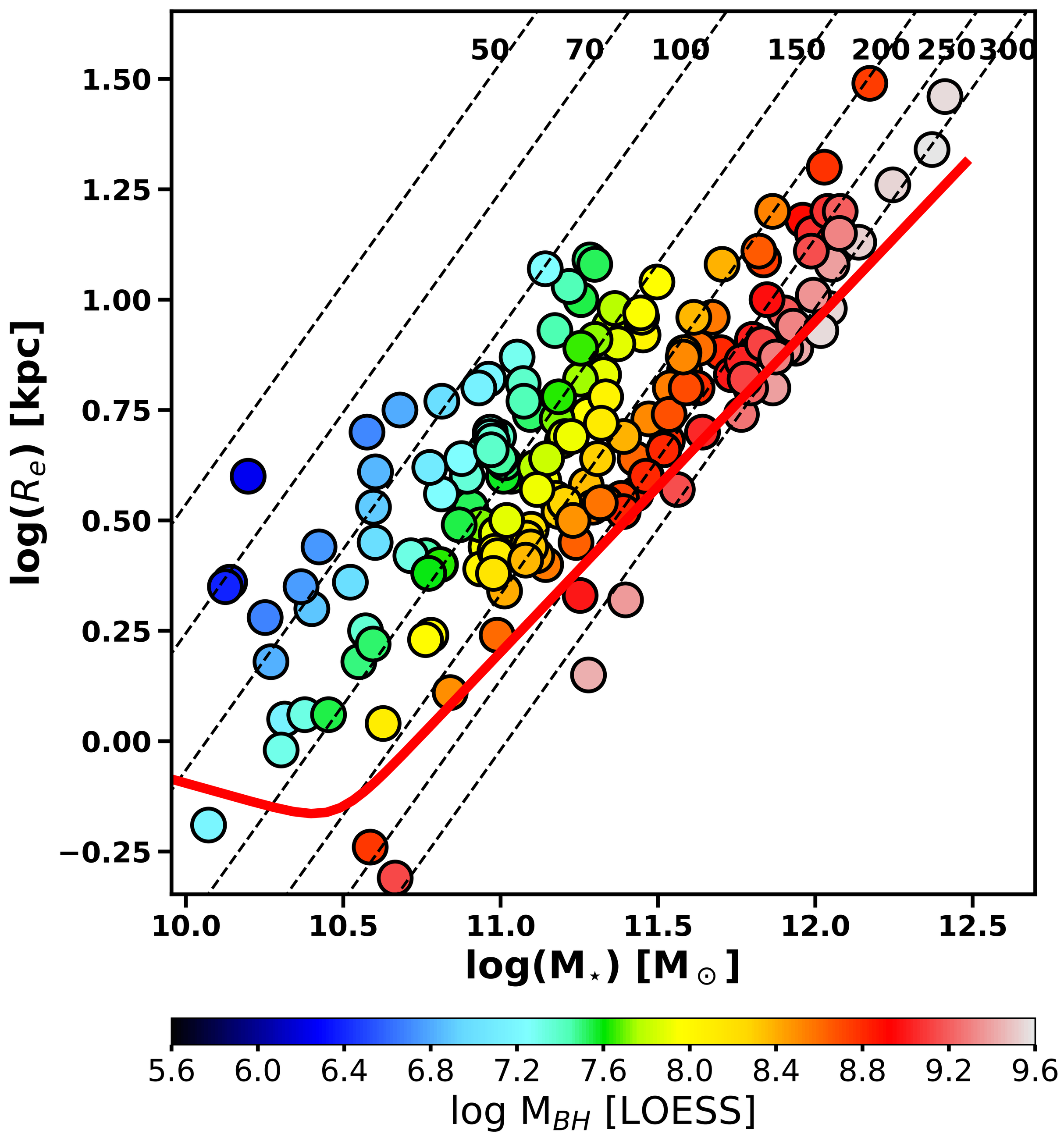
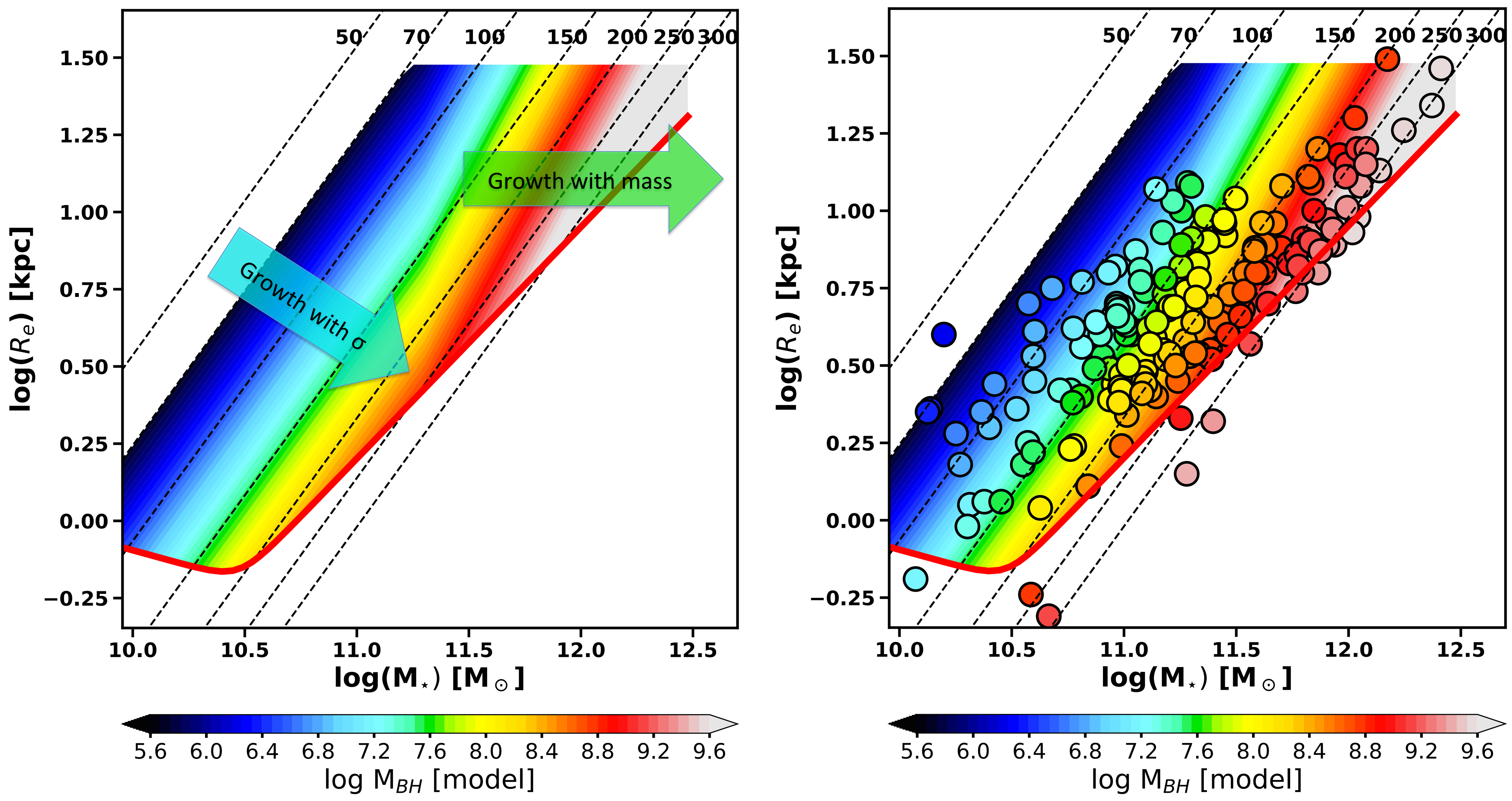
Supermassive black holes on mass – size plane

Supermassive black holes (SMBH) follow tight scaling relations with global properties of host galaxies, implying a symbiotic growth of SMBHs and galaxies. The tightest relation is the relation between the SMBH mass ($M_\bullet$) and stellar velocity dispersion evaluated within half-light radius (σ_e). These relations, however, do not need to be universal, as at different epochs various assembly processes govern the growth of galaxies, and different feeding regimes influence the growth of SMBHs. For example, at high galaxy masses, mergers are predicted to be predominantly gas poor (Khochfar et al. 2009, MNRAS, 307, 506). Such dissipation-less mergers increase the size and the mass of the galaxy, but not its velocity dispersion (Bezanson et al. 2009, ApJ, 697, 1290). SMBHs in remnants of gas-poor mergers do not grow by accretion in an AGN/quasar phase, but through SMBH-SMBH mergers. The consequence is that the most massive galaxies should host SMBHs with masses that do not scale with the global velocity dispersion, but with the mass of the galaxy.



SMBH on the mass – size diagram, *from a compilation of galaxies with measured SMBH masses (van den Bosch 2016, ApJ, 831, 134). Colours indicate SMBH masses ($M_\bullet$), with a range given on the colour-bar. Red line is the "zone–of–exclusion" (Cappellari et al. 2013, MNRAS, 432, 1862). Diagonal dashed lines are lines of constant σ_e. The $M_\bullet$ values were smoothed using the LOESS method (Cleveland 1979, J. Am. Stat. Assoc 83, 596). Note that colours ($M_\bullet$) change with increasing σ_e (as expected from $M_\bullet$ - σ_e relation) until a galaxy mass of M_{crit} > 2×10^{11} $M_\odot$. Beyond that mass the increase in $M_\bullet$ is not necessarily followed by an increase in σ_e. The change is subtle, hindered by a small galaxy mass range (a factor of 3-4) and the large scatter in $M_\bullet$ (a factor of 10), but can be seen in the change of colour along a line of constant σ_e (e.g. for σ_e = 250 km/s).*



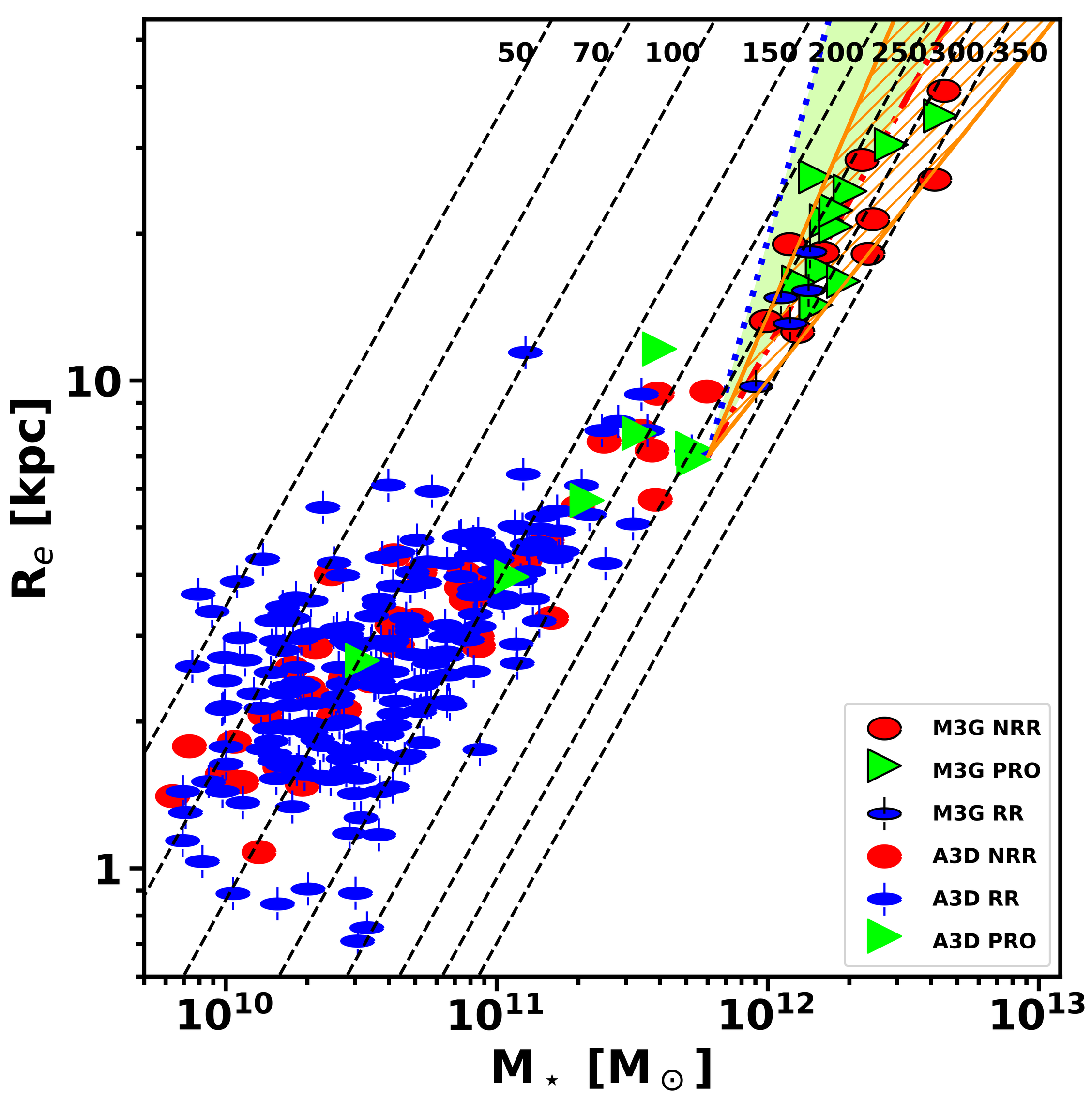
Toy model of SMBH growth. Left: *A toy model of SMBH mass evolution, where $M_\bullet$ grows with σ_e for low mass galaxies and with $M_\star$ for high masses, as indicated by arrows.* ***Right:*** *comparison of the toy model and the data.*

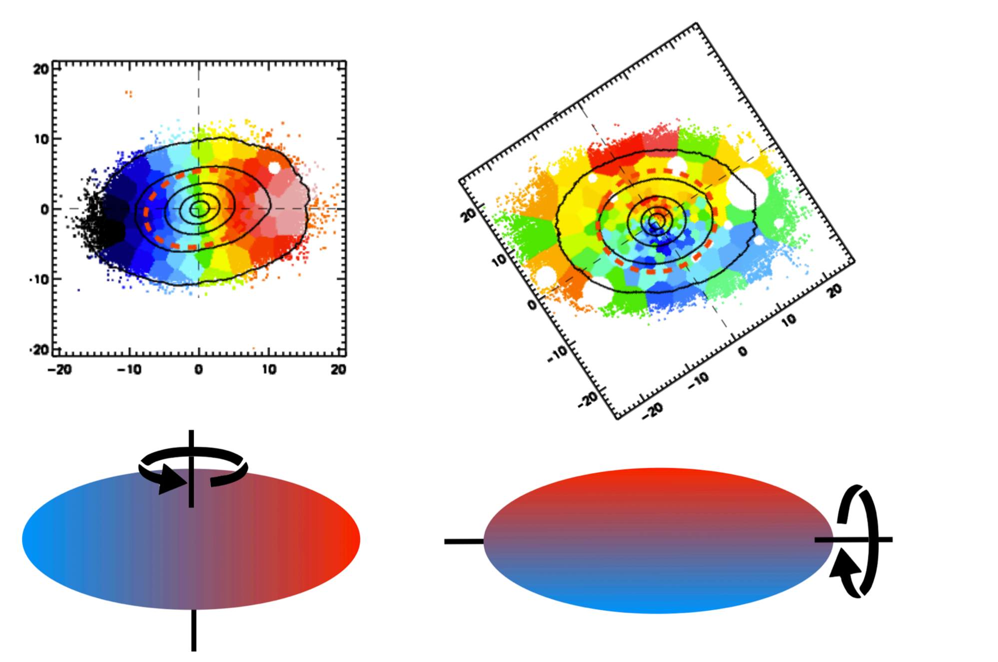
Two growth channels

We construct a toy model based on the assumption that below a critical galaxy mass of 2×10^{11} $M_\odot$ the SMBH grows by accretion of gas. Above the critical mass, SMBH grows via merging. In the first case, $M_\bullet \sim\sigma^{4-5}$ (Silk & Reels 1998, A&A, 331, 1; Fabian 1999, MNRAS, 308, 39), while in the second case, $M_\bullet \sim M_\star$. Galaxies grow in a similar manner: via a channel characterised by the consumption of accreted gas through star-bursts and a channel dominated by accretion of mass (stars formed elsewhere) through dissipation-less mergers (e.g. Rodriguez-Gomes et al. 2016, MNRAS, 458, 2371; Qu et al. 2017, MNRAS, 464, 1659). Linking these two modes of growth for galaxies and SMBHs models can reproduce the behaviour of $M_\bullet$ on the mass – size plane. The model details can be found in Krajnović, Cappellari & McDermid (2018, MNRAS, 473, 5237).

How do the most massive galaxies grow?

The most massive galaxies are typically slow rotators (Emsellem et al. 2011), exhibiting complex kinematics and a low level of rotation. At the highest masses, about 50% of galaxies also show prolate-like rotation (see Fig. 3 top for an illustration). Most massive galaxies also have cored nuclear surface brightness profiles (Krajnović et al. 2013, MNRAS, 433, 2812). The evidence point towards a growth channel specific for the most massive galaxies, which is dominated by major dissipation-less merging. There the SMBH growth is linked with mergers of SMBHs, which introduce a dependence on galaxy mass, and implies non-universal scaling relations.





Evidence for dissipation-less merging. Left*: Mass – size relation for galaxies from ATLAS^{3D} and M3G surveys. The kinematics of M3G galaxies is dominated by prolate-like rotation, an indication of the strong influence of dissipation-less equal mass mergers. Shaded regions indicate locations of remnants of equal mass dissipation-less mergers, starting with 10^{12} $M_\odot$ progenitors.* ***Top:*** *examples of a rotation around the minor axis (typical of galaxies at all masses, and prolate-like rotation (often found in the most massive galaxies.)*

** Based on:*

- *Krajnović, Cappellari & McDermid, 2018, MNRAS, 473, 5237*
- *Krajnović et al. 2018, MNRAS, 477, 5327*