Black Hole Growth in Disk Galaxies Mediated by The Secular Evolution of Short Bars

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Drivers of gas inflows feeding black holes (BHs)

- **Yesterday’s story: Gas-rich major mergers**

- **Challenges:**
  1. 85% AGN hosts have no signature of major merger at $z<1$ (Cisternas et al. 2011);
  2. AGN hosts seems disk-dominated at $z<3$ (Schawinski et al. 2011, Kocevski et al. 2012, Simmons et al. 2012);
  3. Massive BHs exist in disk-dominated galaxies (e.g. Filippenko & Ho 2003; Greene et al. 2010; Simmons et al. 2017)

- Only triggering most luminous quasars and AGNs (e.g., Barnes & Hernquist 1996; Hopkins et al. 2008; Treister et al. 2012)

- **Secular processes:** “bars within bars” (S2B) system and spirals (Shlosman, Frank & Begelman 1989; Hopkins and Quataert 2010; W.-T. Kim & Elmegreen 2017)
Secular processes

- Gas inflows driven by internal non-axisymmetric instabilities.
- The growth of bulge can suppress gas inflows.
- The short inner/nuclear bars should play an important role.

(Hopkins & Quataert 2008)
Basic properties of nuclear/inner bars

- **Common stellar features:** ~1/3 of early-type barred galaxies (e.g. Erwin 2004; Erwin & Sparke 2002; Laine et al. 2002; Erwin 2003, 2004). No clear in late-type.

- **Short:** semi-major axis 0.1-1.3 kpc. Size ratio of inner and outer bars ~ 0.05-0.3, the median value 0.12

- **Generally, rotate faster than its outer counterpart:** driven gas further into the center (Buta & Crocker 1993; Friedli & Martinet 1993; Corsini et al. 2003)

- **Formation mechanism:** the bar instability of a dynamically cold nuclear disk (e.g. Du, Shen & Debattista 2015; Wozniak 2015)

NGC2950 R-band

Outer/primary bar

Inner/nuclear/secondary bar

(Erwin 2008)
I. N-body simulations of S2Bs (Du et al. 2015)

- Initial conditions: exponential stellar disk + unimportant rigid halo
- The dynamical temperature \( \text{Toomre } Q = \frac{\sigma_R \kappa}{3.36 G \Sigma} \) determines the bar and clumpy instabilities of the stellar disk.
- Initial disk: a dynamically cool nuclear disk + a hot outer disk
- Nuclear bars form from the bar instability of nuclear disk.

\[ Q < 1 \quad Q \sim 2 \quad Q > 1 \]

Toomre-Q

Hot outer disk

Q<1

Cool nuclear disk

\[ R \]
II. A realistic S2B model: similar kinematics to observations (Du et al. 2016, 2017a)

- Velocity dispersion humps perpendicular to inner bars (named as sigma-hollows in de Lorenzo-Caceres et al. 2008)
III. Adding a BH (Du et al. 2017b)

- We used a Plummer sphere of softening radius 2.5 pc to mimic BHs.
- The BH mass grows to 0.2%$M_d$ during $t=300-350$ after the S2B structure has reached a steady state.
- Guard shells around BH are used to reduce the time step of calculation.
- The inner bar can be destroyed quickly by a BH of mass 0.2%$M_d$. 

Guard shells
Shen & Sellwood (2004)

$M_{bh} = 0.2\%M_d$
III. I. Evolution of bar amplitudes

- BH mass range $0.0001\% - 0.3\% M_d$

- The growth of $0.05\% M_d$ BHs can break the equilibrium state of S2B structures.

- BHs of mass $0.2\% M_d$ are likely to destroy any kind of short bars (R~1 kpc) quickly.

The hypothetic picture:

- Dissolution of inner/nuclear bars $\rightarrow$ slow down or even stop BH growth

- The maximum BH mass allowed in the secular evolution $0.002M_d$. 
III. II. Mass ratio of BHs and host galaxies

• **Es** and **S/S0 with classical bulges** have larger $M_{bh}/M_*$ ratio (Reine & Volonteri, 2015), because of mergers?

• **S/S0 with pseudo-bulges** and **nearby AGNs** are dominated by the secular evolution: consistent with our predicted maximum $M_{bh}/M_*$ ratio (**0.002**, cyan shaded region).

• **An indirect evidence of that the secular growth of BHs is dominated by inner bar-driven gas inflows.**

Data are adopted from Reine & Volonteri (2015)
III. Robustness of the result

- Verified with a polar-grid code **GALAXY** (Sellwood 2014) and a momentum-conserving treecode **gyrfalcON** (Dehnen 2000, 2014).
- **Single-nuclear barred** models have been tested.
- **The uncertainty of** $M_{bh}/M^*$ **upper limit**: robustness of other non-axisymmetric structures, pre-existing classical bulge
SUMMARY

• Nuclear/inner bars are **fragile** under the dynamical influence of a massive BH.

• The growth of BHs might be self-regulated, thus generating the observed upper limit of $\frac{M_{\text{bh}}}{M^*}$.

• On-going work: the relics of bars destroyed by BHs, bulge?
Thank you!