New Modes of Growing the Lightest Supermassive Black Holes

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Galaxy Awesome

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The Biggest Supermassive Black Holes

Common!

Elliptical Galaxy M87

Rare!

Black Hole Mass

Bulge velocity dispersion (km/s)

Gultekin+ 09
Hook #1 -- What type of gas fuels a light SMBH?
Bellovary et al. 2013

(MOVIE HERE)
Light SMBHs prefer a cold breakfast
Most of the early SMBH growth is not from gas...

...and the gas that does fuel the SMBH is not from mergers!
Hook #2: What if we cook up a MW SMBH only with mergers?

Micic, KHB + Sigurdsson 2011; KHB, Micic, Sigurdsson + Rubbo 2010; Micic, KHB + Sigurdsson 2008; Micic, KHB, Sigurdsson + Abel 2007

(movie here)

The broad approach: zoom-in collisionless n-body simulations to generate merger trees, and incorporate the gas physics semi-analytically.
Recipe for growing the lightest supermassive black holes

We use PopIII stellar remnants as our black hole seeds.

After halos merge, we merge the BHs after a dynamical friction timescale -- assume the final parsec is solved.

Our black holes grow by a combination of direct mergers and galaxy merger-driven gas accretion:

\[ M_{\text{acc}} = M_{\text{BH,0}} \left( e^{\frac{\alpha t_{\text{acc}}}{t_{\text{sal}}}} - 1 \right), \]

\[ \alpha = \left( \frac{M_s}{M_p} - \alpha_0 \right), \]

We add gravitational wave recoil, too -- $10^6$ realizations of possible spins and orientations

Micic, KHB, Sigurdsson 2009
KHB, Micic, Sigurdsson+ Rubbo 2010
see Hirschmann et al; Tanaka et al
We found 3 classes of black holes:

- Massive central
- Slowly sinking
- Ejected
Is SgrA* an oddball?

If kicks are large:
- 20% of halos form proper SMBH

If kicks are small:
- SgrA* is common
Light SMBHs don’t assemble from equal mass (or even nearly equal mass) mergers after the dark ages, there are few major mergers.

KHB et al. 2010
Dwarf galaxies may also have central black holes

see also Micic, KHB 2007, Volonteri + Priya 2009, Peng 2010
Proof in the Pudding? Henize 2-10

Reines et al. 2011
with a prescription built on the merger paradigm....

MW-like SMBHs in MW-like galaxies grow more from minor mergers than from major mergers.

Hook#3 for Dual AGN folks: The Final Parsec Problem is not a problem...
Binary black holes sink closer via 3-body scattering.

$O(10^{10}) \text{ yr}!^{**}$

**in a static, gas-free, spherical galaxy with permanent ejections and no resonances


\[
a_h := \frac{G \mu r}{4 \sigma^2} \sim \frac{1}{4} \frac{q}{(1+q)^2} r_h,
\]

$O(10) \text{ pc}$
The final parsec problem -- refilling a spherical loss cone takes $> t_{Hub}$


$O(10) \text{ pc}$

$O(10^{10}) \text{ yr!}^{**}$

**in a static spherical galaxy with permanent ejections and no resonances
Final Parsec Problem? Not a problem for a non-spherical galaxy!

Expect $10^8 \, M_\odot$ Binary BHs to take less than 3 Gyr to coalesce in an equilibrium axisymmetric galaxy.
Axisymmetric galaxies have low angular momentum orbits that overfill the loss cone.

Li, KHB+Khan in prep

~60% of the stars within the inner 100 pc are saucers
There are lots of ways to plunge through the final parsec:

- Gas
  - Non-equilibrium models: rotation, bar unstable, post merger
  - Extra precession: Post-newtonian and resonant relaxation
  - Triaxiality
  - axisymmetry
    - Kozai -- high eccentricity
    - 3rd black hole
Recap: it’s time to consider deviations from the major merger paradigm

- Most gas fueling may be cold (at least at high redshift/low halo mass).
- The lightest supermassive black holes assemble more from minor mergers than major ones.
Jillian’s next step: spin in cosmo simulations

- On-the-fly 3D spin tracking
- Aid in GW predictions

WORK IN PROGRESS
Come chat with me about:

BH Accretion and spin!

The M-σ relation!

The final parsec problem!

Hypervelocity stars!

Galaxy Flybys as AGN Triggers!

2LPT vs ZA and seed BHs!

and much, much more!
For more information:

Khan, KHB, et al 2013

Bellovary et al. 2013, 2014

Sinha + HB 2012

HB, Wise + Sinha 2012

Palladino, Schlesinger, HB, Allende Prieto, Beers, Lee, Schneider 2013

Lang, HB, Bogdanovic, Sesana, Amaro-SEOane, Sinha, 2013

Micic, HB + Sigurdsson 2011

HB, Micic, Sigurdsson + Rubbo 2010

Micic, HB + Sigurdsson 2008

Micic, HB, Sigurdsson + Abel 2007

P.S. Please cite generously!