Small Scale Black Hole Clustering in Hydrodynamic Simulations: Evidence for Mergers

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Outline

• Basic BH properties
• Large Scale Clustering
  – Implications for host halos
• Small Scale Clustering
  – Effect of mergers
• Observational comparison
Why clustering?

- Black hole clustering can be matched to observed galaxy clustering, or theorized dark matter clustering.
- Strength of clustering helps us understand how BHs populate dark matter halos.
- Can be used to make conclusions about BH environment and fundamental processes.
  - Ex. Strong clustering -> Large DM halos -> rare objects -> long lifetime.
- Luminosity dependence could indicate if bright and faint quasars occupy the same host halos.
Simulations - Gadget3

• N-body + Hydrodynamics (SPH)

• Subgrid Models
  – Star Formation
  – BH Formation
    • Seeded to groups above $5 \times 10^{10} \, M_\odot$
    • Seed BH: $5 \times 10^5 \, M_\odot$ sink particle
  – BH Growth
    • Accretion
    • Mergers
  – BH Feedback

• Simulations:
  – 33.75-50.0 Mpc h$^{-1}$
  – 2.73 kpc h$^{-1}$ softening length
  – $2 \times 486^3$ particles
    • Dark Matter: $2.75 \times 10^7 \, M_\odot$;
    • Gas: $4.24 \times 10^6 \, M_\odot$
Our Black Holes
Our Black Holes

Overall trends with time:
- Increasing number of Bhs
- BHs and groups grow
- Luminosity tends to decrease
**Black hole correlation function**

- Good agreement between two simulations
- Distinct 1-halo and 2-halo terms
- 1-halo dominates below $\sim 300$ kpc $h^{-1}$
Matching Black Holes to Host Groups

- Typical host mass found by matching 2-halo correlation functions for BHs and groups
  - BHs closely trace group clustering
- Slow evolution for full population
- Rapid increase at low redshift for luminous BHs
Small Scale Clustering

- 1-halo term do not agree
Small Scale Clustering

- 1-halo term do not agree
- Improved agreement if restricted to objects within the same host groups
  - Still different shape
- Boost in small scale bias
  - In sufficiently large groups
  - At all redshifts
Small Scale Clustering

- **1-subhalo term:**
  - BH pairs in single galaxy
  - Results of galaxy interactions/mergers
  - Most important in largest groups
  - Steepens small scale correlation function

- **Subdivide 1-halo into '1-subhalo' and '2-subhalo'**
Small Scale Clustering

- Better 2-subhalo agreement when BHs restricted to same host groups as the subgroups
Observational Comparison

![Graph showing observational comparison with different datasets and subgroups in 4–8 \times 10^{11} M_\odot groups.](image)

- Hennawi et al. 2006
- Myers et al. 2008
- PMN 2004
- BHs
- Subgroups

Restricted to:
- Typical Host
- 4–8 \times 10^{11} M_\odot groups

Scale [kpc h^{-1}]
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- Subgroups in 4–8×10^{11} M_\odot groups

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Scale [kpc h^{-1}]
Conclusions

• Large scale clustering matches galaxy clustering
  – Typical host mass increases with time

• Small scale clustering does not match galaxies
  – Caused by merger-induced multiply-occupied galaxies
    • Typically central galaxy
    • Typically no more than one massive BH ($>10^7 M_\odot$)
  – Explains excess in observed signal
  – Reinforces importance of galaxy interactions on black hole evolution
Typical Multiply-occupied Subgroups

- Much more common at low redshift
- Larger groups tend to host more BHs in central SG
- Almost exclusively central subgroups
Typical Co-habitating BHs

- Much more common at low redshift
- Larger groups tend to host more BHs in central SG
- Generally one massive BH with one or more smaller BHs