X-ray halo scaling relations of supermassive black holes


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Black hole - galaxy co-evolution

- Black hole mass is known to correlate with host galaxy properties.
- Correlation observed both with stellar content (K-band luminosity) and dynamics (velocity dispersion).

Kormendy & Ho 2013
The impact of AGN on galaxy evolution

The galaxy luminosity function does not follow the expectations of DM halo formation models.
Including (tuned) AGN feedback

BAHAMAS simulation, McCarthy et al. 2017

\[ \phi(M_*) (\text{Mpc}^{-3} \text{dex}^{-1}) \]

\[ \log_{10}[M_*(M_\odot)] \]

\[ M_{500, \text{x-ray}} / M_{500, \text{x-ray}} \]

\[ \log_{10}[M_{500, \text{x-ray}}(M_\odot)] \]
Brightest Cluster Galaxies (BCGs) are the largest galaxies in the Universe ⇒ They should host the most massive BHs

McConnell et al. 2011: $M_{BH}$ measurements in BCGs exceed the expectations of the $M - \sigma$ relation by an order of magnitude

McConnell et al. 2011

A85, Mehrgan et al. 2019
AGN feedback in cluster cores

AGN jets and outflows inject energy in the surrounding medium and offset cooling
"Cooling flows" in galaxy clusters

In the cores of relaxed clusters, densities are high
⇒ Strong X-ray emission, low $T$, $t_{\text{cool}} \ll \frac{1}{H_0}$

The cooling of the gas in nearby clusters is largely suppressed (by factors 10-100)

McDonald et al. 2018
Large (≈ 200 kpc) filaments of warm ($H\alpha$) gas are found in and around BCGs.

The location of the filaments coincides with the coolest X-ray gas.

*NGC 1275, Fabian et al. 2008*
Large ($\sim 200$ kpc) filaments of warm ($H\alpha$) gas are found in and around BCGs.

The location of the filaments coincides with the coolest X-ray gas.

The filaments are not gravitationally supported; infall.
The self-regulated AGN feedback loop

Gaspari & Sadowski 2018
$M_{BH}$ correlates with hot halo properties

We selected a sample of 85 massive galaxies, galaxy clusters and groups with archival dynamical BH mass measurements and measured X-ray halo properties.
Comparison with optical scaling relations

The scatter of the $M_{BH} - T_X$ relation is smaller than both the stellar mass ($L_K$) and velocity dispersion scaling relations.
Can hot (Bondi) accretion explain the results?

The direct hot gas accretion rate can be written as
\[ \dot{M}_{BH} \propto M_{BH}^2 \rho_{\text{gas}}/c_s^3 \propto M_{BH}^2 K_{\text{gas}}^{-3/2} \]
Can hot (Bondi) accretion explain the results?

- The direct hot gas accretion rate can be written as 
  \[ \dot{M}_{BH} \propto M_{BH}^2 \rho_{gas} / c_s^3 \propto M_{BH}^2 K_{gas}^{-3/2} \]

- \( M_{BH} \) does not correlate with the Bondi rate
Here the gas cools down first and then accretes; the accretion rate is proportional to the amount of gas cooling down: $\dot{M}_{BH} \propto L_X / T_X$
“Precipitation” a.k.a. chaotic cold accretion (CCA)

- Here the gas cools down first and then accretes; the accretion rate is proportional to the amount of gas cooling down: $\dot{M}_{BH} \propto L_X / T_X$

- The integrated CCA mass (assuming a high duty cycle) is well correlated with and comparable to the total $M_{BH}$

![Graph showing correlation between $M_{*, cca, c}$ and $M_{*, cca, c}$ with intercept, slope, scatter, and correlation coefficient values.]
What about mergers?

- In the bottom-up structure formation paradigm the BHs of the merging entities should also merge.

Bassini et al. 2019
What about mergers?

In the bottom-up structure formation paradigm the BHs of the merging entities should also merge.

Major BH mergers are rare; the total accreted mass exceeds the mass gained in successive mergers (Bassini et al. 2019).

Bassini et al. 2019
The mass of SMBH correlates with host halo properties; excess at high mass

BH masses in massive systems correlate with hot halo properties; smaller scatter than $L_K$ and $\sigma_v$

BH masses do not correlate with Bondi rate; cooling + accretion scheme needed

In galaxy clusters AGN outflows offset cooling by injecting energy

The self-regulated feedback cycle implies large accreted masses over cosmological timescales

Mergers participate to the growth but cannot explain masses of $10^{10} M_\odot$

Take home message