The Black Hole-Galaxy Connection in the RomulusC Simulation
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Introduction

The RomulusC simulation is a zoom-in simulation of a $1.5 \times 10^{14}$ solar mass halo using improved prescriptions for black hole accretion and dynamics [1,2]. This is an ideal simulation to better understand how supermassive black holes (SMBHs) grow in a dense environment. To this end, we retrace the histories of 228 galaxies in the simulation with at least $10^9$ solar masses in stars.

Some questions that we intend to address are:
• How do the most massive SMBHs in the universe assemble their mass?
• How well does SMBH accretion trace the star formation rate?
• Are there phenomena special to clusters that affect SMBH assembly?

The M87 jet in the Virgo cluster

The Central Black Hole

The brightest cluster galaxy (BCG) of RomulusC has a SMBH which reaches 14 billion solar masses at $z=0$. When does it assemble this mass?

We compare the mass of the most central black hole in RomulusC to predictions from a semi-analytic model developed concurrently [3]. The model is able to reproduce and explain properties of the AGN population out to $z=6$.

In agreement with the semi-analytic model, only 10% of the final mass is assembled by $z=3$. According to the model, the remaining mass should be assembled through the combination of merger-triggered bursts, a steady accretion mode, and black hole mergers. (However, the semi-analytic model predicts a final mass that is an order of magnitude lower.)

Ram Pressure and AGN Activity

It has recently been reported that the active galactic nuclei (AGN) fraction is high among galaxies undergoing strong ram pressure stripping [6]. We report that many galaxies in RomulusC indeed exhibit bursts of AGN activity, as well as star formation, when undergoing strong ram pressure.

One example is shown here on the left: a galaxy with a stellar mass of $1.3 \times 10^{10}$ solar masses at $z=6$. Star formation and rescaled black hole accretion are shown in blue and green, respectively. The dashed yellow line is the incident ram pressure, estimated using spherical cluster gas density profiles with the formula of [7].

Theoretical studies suggest that a threshold of roughly $2.5 \times 10^{10}$ Pa may trigger a starburst and an AGN (see e.g., [8]), and this threshold is very much exceeded here. Intriguingly, the burst of black hole accretion is delayed with respect to the burst of star formation, a common phenomenon in RomulusC.

Black Hole Accretion and Star Formation

At each epoch, we compute BHARs and SFRs averaged over the past 250 Myr. This is plotted on the left, color-coded according to stellar mass. Since the AGN Main Sequence is only defined for star-forming galaxies, we only keep galaxies on the star-forming main sequence. The grey band is a not a fit—this is the relation from [4]. In no way is the SMBH accretion model tuned to reproduce this relation.

Interestingly, this relation does not appear to evolve with redshift. The scatter increases as we decrease the time over which the average is taken, suggesting that AGN variability is the reason the AGN Main Sequence is only observed via stacking.

Next Steps

Stacked X-ray observations of star-forming galaxies find that black hole accretion rate (BHAR) appears to trace the star formation rate (SFR) [4]. This has been called the “AGN Main Sequence.”

At each epoch, we plot the growth vectors in the black hole mass-stellar mass plane going back 250 Myr at each epoch. A corollary of the AGN Main Sequence is that black holes only grow as fast as their galaxies. If a galaxy has an over-massive black hole, it moves to the right of this plot. Once the stellar mass catches up, the galaxy moves diagonally upwards. This is what is indeed what is seen when tracing the flow pattern, and the vectors are color-coded by angle to emphasize this feature. The dashed line is again not a fit—this is a black hole mass to stellar mass ratio of 0.5%, appropriate for local elliptical galaxies [5].

We have shown that the central black hole grows 10% of its mass by $z=3$, the AGN Main Sequence holds for star forming galaxies, and that ram pressure can increase the black hole accretion rate. Here are some additional phenomena we would like to explore:

• Examining the effects of mergers and fly-bys
• Galaxy morphology, especially during high ram pressure events.
• Comparing the AGN main sequence in the field (Romulus25).
• Characterizing the population of wandering black holes.

References


More Info

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To learn more about the RomulusC simulation, see Michael Tremmel’s talk on Thursday morning!