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SIMULATING THE CO-EVOLUTION OF GALAXIES AND THEIR SUPERMASSIVE BLACK HOLES

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EXECUTIVE SUMMARY

We performed high-resolution simulations following the formation and evolution of galaxies from the Big Bang to the present time. We focused on galaxies more massive than the Milky Way, which represent the frontier for high-resolution simulations of galaxy formation and that host the most massive black holes in the universe. We are using the simulations to study how galaxies and the supermassive black holes they host at their centers co-evolve. These new simulations, which pushed the dynamic range of galaxy formation simulations by about an order of magnitude relative to the previous state-of-the-art, will have legacy value in enabling a wide range of other scientific investigations, including studies of the gaseous halos of massive galaxies.

RESEARCH CHALLENGE

Observations indicate a close connection between the growth of supermassive black holes (SMBHs) and the evolution of their host galaxies. For example, the masses of SMBHs correlate tightly with the stellar bulges of galaxies. The cosmic history of SMBH growth also roughly tracks the cosmic star formation history. Furthermore, SMBHs appear important in explaining the observed properties of the most massive galaxies, which are observed to have stopped forming stars long ago. However, the physical mechanisms driving this connection remain largely unknown. This is because the huge dynamic range of physical scales involved has so far made it extremely challenging to simultaneously simulate all the relevant dynamics. Key questions include: What is the origin of galaxy–black hole scaling relations? How is active galactic nucleus (AGN) activity triggered? What is the impact of AGN feedback on galaxy evolution? What are the effects of stellar feedback on SMBH growth?

METHODS & CODES

To produce our galaxy formation simulations, we used the GIZMO N-body+hydrodynamics code. GIZMO is a publicly available and highly scalable code that implements state-of-the-art gravity and hydrodynamic solvers. Our simulations also build on a set of modules for galaxy formation physics developed as part of the FIRE (Feedback In Realistic Environments) project.

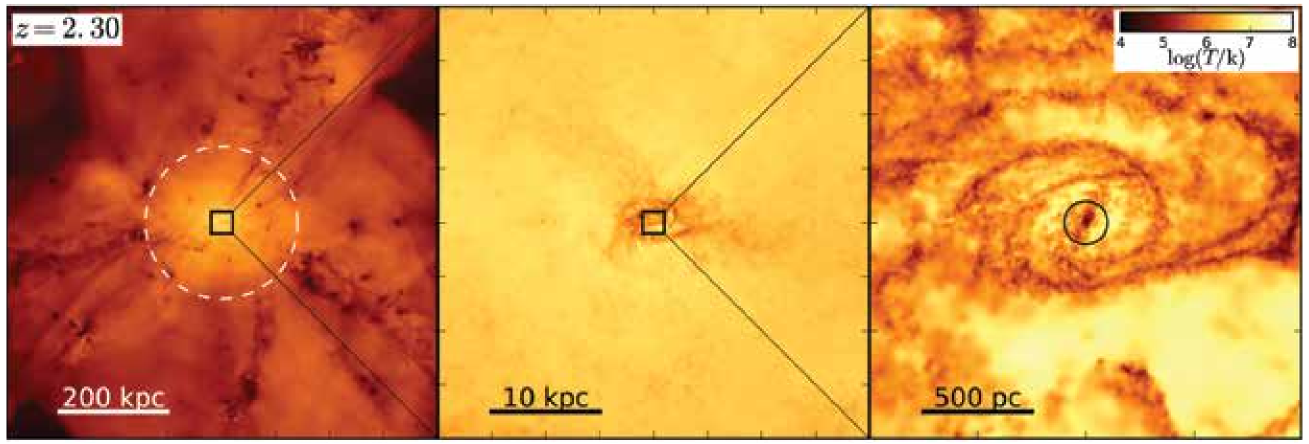

Figure 1: Multiscale rendering of the gas distribution (color scale indicates temperature) in one of the simulations of a massive galaxy with a central supermassive black hole (Anglés-Alcázar, et al., 2017). The leftmost panel shows the large-scale distribution of matter (the dashed circle indicates the size of the dark matter halo) and the rightmost panel focuses on the galactic nucleus.

RESULTS & IMPACT

Scientifically, the new simulations pushed the dynamic range of galaxy formation simulations by about an order of magnitude and will enable a wide range of scientific investigations beyond supermassive black holes. Pushing our simulations to the scale of this allocation also enabled us to test and optimize the scaling of cosmological zoom-in simulations in a new regime. Since a version of GIZMO is publicly available, this optimization will benefit the broader high-performance computing community.

WHY BLUE WATERS

The Blue Waters computational capabilities are essential to simulate at high resolution the massive galaxies in which most supermassive black hole growth occurs, as these simulations require the largest number of resolution elements.

PUBLICATIONS & DATA SETS

Anglés-Alcázar, D., et al., Black Holes on FIRE: Stellar Feedback Limits Early Feeding of Galactic Nuclei. *MNRAS Letters*, 472 (2017), p. L109.