SUPERMASSIVE BLACK HOLES AT THE COSMIC FRONTIER

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EXECUTIVE SUMMARY

The BlueTides (BT) cosmological simulation is unique because it directly probes the range of scales (masses and epochs) of galaxies that are likely to be discovered in the near future (for example, by the James Webb Space Telescope (JWST), the successor to the Hubble).

In this project, we have extended the BT simulation to cover the evolution of the first billion years of cosmic history (BlueTidesII). At this epoch, there are additional, already-existing observations that tell us that the first billion-solar-mass black holes (also known as quasars) had already formed. It is important to make contact with observations of quasars, which have not been discovered at these early stages of cosmic history. The extreme early growth depends on the early interplay of high cosmic gas densities and low tidal fields that shape the mode of accretion and allow this first generation of massive black holes to form at the most rapid pace. We have tracked the descendants of the first supermassive black holes in today's universe by running a new BT MassTracer pathfinder simulation that follows the same volume of BlueTides simulation all the way to z=0 (current universe) at a decreased resolution.

RESEARCH CHALLENGE

Computational cosmology, simulating the entire universe, represents one of most challenging applications for the era of petascale and beyond computing resources. We have successfully carried out a full-machine run on Blue Waters, the BlueTides cosmological simulation. The run was made possible through our new code, Massively Parallel (MP)-Gadget. The simulation has proven to be crucial to understanding the formation of the first quasars and galaxies from the smallest to the rarest and most luminous, and their effect to reionization. The simulation is being used to make predictions about what the WFIRST and JWST (expected to launch in 2018) will see. The largest next-generation telescopes (ALMA, JWST, WFIRST) currently planned aim to study the "end of the dark ages," an epoch in the early universe when the first galaxies and quasars form and reionization of the universe takes place. The fundamental challenge to understanding this epoch is that extremely large volumes need to be simulated while at the same time extremely high resolution is required. Our BT run on Blue Waters is the first and only cosmological simulation of structure formation that has run on the full Blue Waters machine.

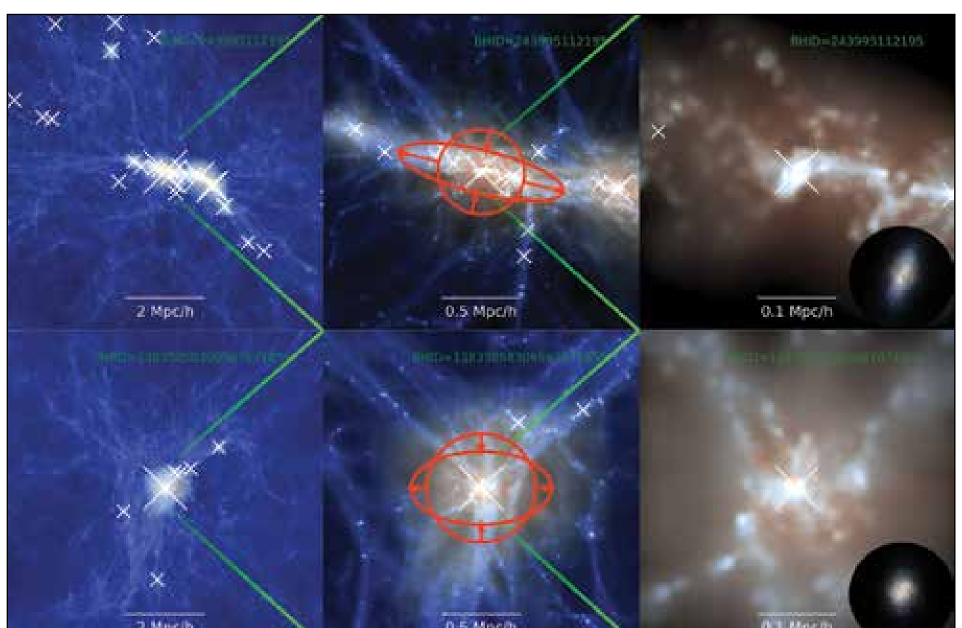

Figure1: The environment of the most massive disk galaxy (top row) compared to the most massive black hole and host galaxy (bottom row) at different scales. The orange ellipses and arrow illustrate the tidal field components in the two cases. Tidal fields stretch material along one direction and compress material along the perpendicular.

In the last year, we have extended the BT simulation with an unprecedented volume and resolution to cover the evolution of the first billion years of cosmic history (BlueTidesII). The goal is to increase significantly the scientific impact to the research community of this calculation. At this later epoch, there is a wealth of additional existing observations that we would be able to compare to directly validate our models.

METHODS & CODES

The run was made possible through our new cosmological hydrodynamic simulation code Massively Parallel (MP)-Gadget. Recent radical updates to the code efficiency, and also to the smoothed-particle hydrodynamics formulation and star formation modeling, mean that we are able to meet the challenge of simulating the next-generation space telescope fields and effectively use the full Blue Waters machine. We have extended the BT run, which has an unprecedented volume and resolution, to cover the evolution of the first billion years of cosmic history.

RESULTS & IMPACT

We have run BT forward toward the epoch of observed quasars. The growth of the most massive black holes in the early universe, consistent with the detection of highly luminous quasars when the universe is less than a billion years old, implies sustained, critical accretion of material to grow and power them. It is still uncertain which conditions in the early universe allow the fastest black hole growth. Large-scale hydrodynamical cosmological simulations of structure formation allow us to explore the conditions conducive to the growth of the earliest supermassive black holes.

We used BlueTides to follow the earliest phases of black hole critical growth. At a few hundred thousand years after the Big Bang, we have shown that the most massive black holes approach 400 million solar masses. Examining the large-scale environment of hosts, we find that the initial tidal field is more important than overdensity in setting the conditions for early black hole growth. In regions of low tidal fields gas accretes "cold" onto the black hole and falls along thin, radial filaments straight into the center, forming the most compact galaxies and most massive black holes at earliest times. We have pushed the evolution of this large volume some 50 million years further and we have seen that this initial exponential growth of the first supermassive black holes is quenched even at redshift 7. This is exciting; we are starting to see effects of so-called feedback, as there are already hints in observations that this process is in action even in the first quasars.

To explore the question of where the most massive early-forming quasars are today, we have run a dark matter-only cosmological simulation that has the same volume and initial conditions of the BTMassTracer. The lower resolution allowed us to run all the way to the present universe. The results are extremely interesting: The most massive black holes that form in the early universe are not the most massive ones today and are not found in the most massive galaxy clusters. With BTMassTracer, we have traced the descendants of this first generation of supermassive black holes and found that they are in moderately massive galaxies today. In some way, the first black holes have a very fast initial growth phase, but other black holes that assemble later are likely to grow in higher-density regions. The first massive black holes are not in very special places in the overall density field of the universe.

WHY BLUE WATERS

From the simulation/theoretical perspective, large-scale uniform volume hydrodynamic simulation of the high-redshift universe is a problem that is perfectly suited to the largest modern petascale facilities such as Blue Waters. This is because it is now feasible to run memory-limited computations with the resources that computer time allocation panels are able to grant, and so reach unprecedented volumes and resolutions.

PUBLICATIONS AND DATA SETS

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Waters, D., et al., Monsters in the dark: predictions for luminous galaxies in the early Universe from the BLUETIDES simulation. Mon Not R Astron Soc Lett, 461:1 (2016), pp. L51–L55.

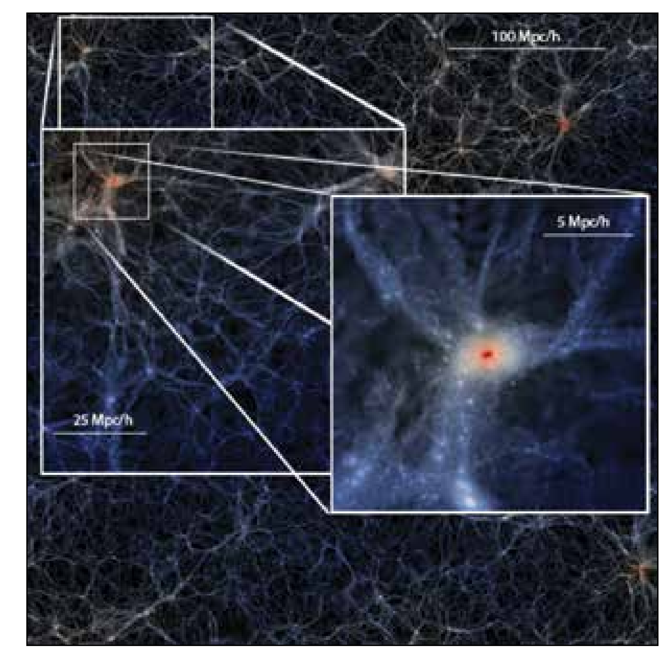

Figure 2: The descendant in today's universe of the massive black hole in BlueTidesII (shown in Fig.1). The images show the dark matter density in a slice through the entire BTMassTracer simulation. the intensity and color of the pixels is representative of the density.