Tracing the high-z hierarchical growth of galaxies with black hole mergers

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The study of the early growth of galaxies and structure is one of the frontiers of cosmology. Some of the most important growth occurs during the "dark ages," when the universe was filled with neutral hydrogen and opaque to all but low frequency photons (like the CMB). Models suggest that the first stars and quasars began to ionize this gas at $z \simeq 20$, with reionization complete by $z \simeq 6$. Measurements of this "Epoch Of Reionization"" (EOR) signature, tracking reionization using hydrogen's 21-cm hyperfine transition, promise to sharpen our understanding of how the infant universe grew the structures we see today.

A critical ingredient in the growth of galaxies is the growth of the black holes (BHs) found in the centers of nearly all galaxies in the local universe. It is especially difficult to explain the 10^9 – $10^{10}\,M_\odot$ supermassive BHs seen in quasars at $z \sim 7$ if (as is typically modeled) one starts from low mass seeds at $z \sim 10$ or higher. Attempts to understand how large BHs formed so quickly indicate that mergers play an important role.

Galaxies hosting BHs at their cores will undergo mergers at some point in this evolution. By various mechanisms, these BHs can be brought together and then merge. Many estimates of the merger rates have been made for different scenarios of BH formation and initial growth. Even the more pessimistic rates suggest multiple events per year occur during the EOR era. Tracing the mergers of these BHs during the epoch $6 \leq z \leq 20$ will provide another method of understanding the early growth of structure, complementing EOR probes which will study this era in the next decade.

The gravitational waves (GWs) produced by these mergers will be rich with information about these early BHs. Their low-frequency GWs can be measured using a space-based GW detector. These events' measured GWs will determine the sources' masses, spins, and distances, often with good accuracy. GWs actually determine redshifted masses: We measure $(1 + z)m$ rather than m. By determining distance and assuming an underlying cosmography, we can invert for redshift and thereby learn how masses and spins evolve with z. Spin information and its evolution is especially important because it describes how the mass of the BHs is built. It tells us whether mass was accumulated randomly (leading to small spins), or whether a preferred direction like the plane of the galaxy has a strong influence (leading to high spins).

Given the value in coordinating these two sources of data about the earliest growth of structure in our universe, we advocate a program to develop space-based low-frequency GW measurements. It is important to understand how well an instrument like eLISA ("evolved LISA," a mission being investigated as a candidate for an ESA-led large mission under the ESA Cosmic Vision Programme) can measure BH properties from mergers in this redshift epoch, and how one might realistically go beyond this. For example, a 3-armed GW antenna substantially improves the ability to determine source distance (and hence redshift) as compared to a 2-armed design (like eLISA). Thinking even longer term, it may be interesting to consider flying multiple eLISA-like antennae. This may make it possible to pinpoint the position of merging high redshift binaries accurately enough to enable cross-correlation with EOR maps of reionization bubbles.