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An AGN disk channel for binary black hole mergers

Active galactic nucleus (AGN) disks have been proposed as promising locations for producing some of the detected stellar mass binary black hole (BBH) mergers since the first discovery of a transient gravitational-wave (GW) signal by the two detectors of the Laser Interferometer Gravitational-Wave Observatory. However, the validity of the AGN disk channel for BBH mergers remains unconfirmed due to the recent isolated binary simulations. In this work, we perform a series of high-resolution 2D hydrodynamical simulations of equal-mass binary black holes (BBHs) embedded in AGN disks to study whether these binaries can be driven to merger by the surrounding gas. We find that the gravitational softening adopted for the BBH has a profound impact on this result. When the softening is less than ten percent of the binary separation, we show that, in agreement with recent simulations of isolated equal-mass binaries, prograde BBHs expand in time rather than contract. Eventually, however, the binary separation becomes large enough that the tidal force of the central AGN disrupts them. Only when the softening is relatively large do we find that prograde BBHs harden. We determine through detailed analysis of the binary torque, that this dichotomy is due to a loss of spiral structure in the circum-single disks orbiting each BH when the softening is a significant fraction of the binary separation. Properly resolving these spirals – both with high resolution and small softening – results in a significant source of binary angular momentum. Only for retrograde BBHs do we find consistent hardening, regardless of softening, as these BBHs lack the important spiral structure in their circum-single disks. This suggests that the gas-driven inspiral of retrograde binaries can produce a population of compact BBHs in the GW-emitting regime in AGN disks, which may contribute a large fraction to the observed BBH mergers.

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