

Bright sirens, dark sirens and gravitational-wave cosmography

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Gravitational-wave observations of compact-binary coalescences provide a direct measurement of luminosity distance. If the redshift of the source can also be determined, these events can be used as standard sirens to construct a Hubble diagram and probe the expansion history of the Universe. In practice, however, identifying the host galaxies of gravitational-wave sources is extremely challenging because of their large sky-localization uncertainties. GW170817 was an exceptional multi-messenger event: its electromagnetic counterpart enabled the identification of both the binary neutron-star nature of the source and its host galaxy. Most gravitational-wave events detected so far, however, are binary black-hole mergers, which are not expected to produce detectable electromagnetic radiation. These “dark sirens” therefore lack direct host-galaxy identification, and statistical methods using galaxy catalogs have so far yielded only limited constraints on the Hubble constant. This situation could change dramatically with gravitational-wave detectors sensitive to frequencies lower than those accessible to current ground-based observatories. If inspiraling binary black holes can be observed from frequencies around 0.1 Hz, the signals may remain in band for weeks to months before merger. Over such long observation times, the changing orientation and velocity of the detector due to the Earth’s rotation and orbital motion induce characteristic modulations in the gravitational-wave signal. These modulations can significantly improve measurements of both the luminosity distance and sky position of the source. Several detector concepts targeting the mid-frequency gravitational-wave band have been proposed. We show that such detectors could localize some dark sirens with sufficient accuracy, in both sky position and distance, to uniquely identify their host galaxies. This would enable the construction of an accurate gravitational-wave Hubble diagram independent of traditional electromagnetic distance indicators, opening a new route to measuring the cosmic expansion history.

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