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LIGO, Virgo, KAGRA and Beyond: The Future of Ground-Based Gravitational Wave Observatories

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The LIGO and Virgo gravitational-wave (GW) detectors confidently detected eleven GW signals during their first two observing runs, from 2015 to 2017. Ten of these were binary black hole mergers, with total system masses ranging from about 18 to 85 solar masses. The remaining event was the spectacular binary neutron star merger GW170817, which was accompanied by a short-hard gamma-ray burst, a distinctive "kilonova" light curve signature traced out by UV/visible/IR telescopes around the world for weeks, and afterglow emission detectable in X-ray and radio for months. This event proved the rich possibilities of multi-messenger astronomy involving gravitational-wave events. The Advanced LIGO and Virgo observatories began their third observing run, O3, in April 2019, with better sensitivities and thus an expectation that many more GW events will be detected in this year-long run. Candidate events are being shared with the community in public alerts. The KAGRA detector in Japan is being commissioned with the goal of joining LIGO and Virgo for the later part of the O3 run.

Projects to upgrade LIGO and Virgo further (A+, AdV+) are now getting underway. Construction of a third LIGO observatory, in India, is scheduled to begin soon and the observatory is projected to come online in 2025. Thus, by the mid-2020s there will be five highly sensitive observatories operating as a coherent network. With a substantial rate of detected events, excellent all-sky response and good localization, this network will offer many opportunities for multi-messenger science with astronomical facilities on the ground and in orbit. Also, "third-generation" (3G) design studies are now exploring the benefits of new, larger observatories with advanced interferometer technologies which could reach an order of magnitude farther into the universe, sampling the cosmological evolution of GW sources and what they can tell us about stellar and galactic astrophysics over cosmic time. In all phases, multi-messenger science will significantly extend the scientific reach beyond what can be learned from gravitational waves alone.

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