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Neutron Star Mergers as a Probe of Neutrino Mass via Gravitational Wave and Neutrino Timing

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Next-generation neutrino experiment Hyper-Kamiokande is expected to detect the diffuse supernova neutrino background (DSNB) over a decade-long observation. While supernovae have received considerable attention, binary neutron star (BNS) mergers represent a complementary, yet largely unexplored, diffuse neutrino source. The landmark multi-messenger detection of GW170817 demonstrated the potential of combining gravitational waves and gamma-rays to probe physics at cosmological distances. Motivated by such multi-messenger observation, we study neutrinos from BNS mergers and show that Hyper-Kamiokande could detect approximately one neutrino event from BNS mergers over 10-20 years of operation, depending on the mergers profile and luminosity models. We demonstrate that such events can be confidently associated with their progenitor mergers using time correlation from advanced gravitational-wave detectors and a neutrino detector, with minimal risk of misidentification against DSNB backgrounds. Further, upon identifying a neutrino event from a neutron star merger, the relative timing between the neutrino and gravitational-wave signals will allow us to place constraints on the neutrino mass. We perform simulations that incorporate relevant uncertainties, including those corresponding to the neutrino emission time and the location of the merger, and find that the resulting sensitivity to the lightest neutrino mass surpasses both the strongest terrestrial bounds from KATRIN and astrophysical projections from galactic supernovae, where the latter are limited by much shorter baselines compared to the typical distances of binary neutron star mergers. Additionally, we extend this analysis to constrain the graviton mass and its velocity dispersion, finding projected limits significantly stronger than current laboratory bounds.

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