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Today's Discoveries, Tomorrow's Frontiers: Multi-Messenger Astrophysics

Multi-messenger events involving gravitational waves (GWs) offer an unparalleled view into some of astrophysics' most profound mysteries. To date, detections have been limited to mergers of neutron stars and black holes - the powerhouses behind the universe's brightest emission: short-duration gamma-ray bursts (GRBs). However, recent observations of long GRBs accompanied by kilonovae have revealed an unexpected new class of long-duration GRBs originating from binary mergers, challenging our understand of the engines driving GRBs - are they neutron stars or black holes?

In this talk, I will present a unification model that elucidates the engines of short and long GRBs, linking these explosive events to the underlying binary populations. This framework allows us to directly associate the distinctive signatures of mergers with their astrophysical origins. I will conclude the talk by exploring what future multi-messenger detections might uncover - particularly the possibility of detecting the first GW signals from non-merger events. I will demonstrate how accretion disks in rapidly rotating collapsing stars can generate coherent and vigorous GWs, and, when coupled with their supernova electromagnetic signatures, these sources could be prime candidates for the inaugural non-inspiral multi-messenger detection by LIGO.

Primary author: GOTTLIEB, Ore (CCA, Flatiron Institute)

Presenter: GOTTLIEB, Ore (CCA, Flatiron Institute)

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