Thesis abstract P. Stevens

"Study of an innovative scheme for frequency–dependent squeezing in third generation gravitational–wave detectors"

Gravitational–wave astronomy has transformed our understanding of the universe since the first detection of GW150914, confirming Albert Einstein's prediction. Over 300 events have been observed by LIGO and Virgo, with KAGRA joining in 2019. Additionally, multi–messenger observations, such as GW170817, allow more complete studies of astrophysical phenomena. These achievements result from decades of international effort to develop kilometer-scale interferometric gravitational wave detectors with sensitivities limited notably by quantum noise arising from quantum uncertainties of photons. As this is one of the most dominant sources of noise, mitigating quantum noise is essential, and frequency–dependent squeezing allows for reducing it across the detection band via two–mirror cavities. This thesis investigates the optical properties of three–mirror cavities as a means to enhance frequency–dependent squeezing in future third–generation gravitational wave detectors. A theoretical model of electromagnetic field propagation is developed to study resonance splitting. The stability of the cavity is then analyzed as a function of its configuration. Additionally, the equivalence between a three–mirror cavity and a two–mirror cavity with variable finesse is presented. Two potential applications are explored for the Einstein Telescope: replacing two two–mirror filter cavities with a single three–mirror cavity using resonance splitting, or substituting individual two–mirror cavities with a three–mirror cavity to exploit variable–finesse behavior. Simulations are used to assess feasibility, tunability, and sensitivity to length control and misalignment, while experiments investigate the resonance splitting and variable–finesse properties.