Achieving Quantum Limits of Exoplanet Detection and Localization

Nico Deshler, Sebastiaan Haffert, Amit Ashok

Discovering exoplanets in orbit around distant stars via direct imaging is fundamentally impeded by the high dynamic range between the star and the planet. Coronagraphs strive to increase the signal-to-noise ratio of exoplanet signatures by optically rejecting light from the host star while leaving light from the exoplanet mostly unaltered. However it is unclear whether coronagraphs constitute an optimal strategy for attaining fundamental limits relevant exoplanet discovery. In this work, we report the quantum information limits of exoplanet detection and localization specified by the Quantum Chernoff Exponent (QCE) and the Quantum Fisher Information Matrix (QFIM) respectively. In view of these quantum limits, we assess and compare several high-performance coronagraph designs that theoretically achieve total rejection of an on-axis point source. We find that systems which exclusively eliminate the fundamental mode of the telescope, without attenuating higher-order orthogonal modes, are quantum-optimal in the regime of high star-planet contrasts. Importantly, the QFIM is shown to persist well below the diffraction-limit of the telescope, suggesting that quantum-optimal coronagraphs may further expand the domain of accessible exoplanets.