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A noise transfer functions calculation method under dynamic orbital conditions for time-delay interferometry combinations

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Space-borne gravitational wave detectors suppress overwhelming laser phase noise by recombining time-delayed heterodyne beatnote phases via time-delay interferometry (TDI). Simultaneously, TDI reshapes secondary noises in the phase, quantified through frequency-domain transfer functions. The dynamic orbits of the detectors modulate secondary noise by affecting arm length variations, which couples into these transfer functions. We propose using a Fourier series to parameterize arm lengths. This yields an analytical method for calculating noise transfer functions applicable to dynamic configurations for arbitrary TDI combinations. Using this method, we analyze three kinds of TDI combinations. For some TDI combinations, the secondary noise transfer functions remain identical under both static equal-arm and dynamic triangular configuration assumptions. However, for zero-response combinations, the static equal-arm configuration assumption renders their secondary noise transfer functions to zero. Thus, the transfer functions must be defined under dynamic triangular configuration conditions. For the T[X, Y, Z] channel, the secondary noise transfer function under the static equal-arm triangular configuration assumption is 2-3 orders of magnitude lower than under dynamic triangular configuration assumptions. The proposed calculation method better aligns with realistic detector constellations, helps improves instrumental noise estimation accuracy, and reduces data post-processing time.

Presenter(s) : ZHAO, Xinlei

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