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Stray light noise from dust particles falling inside Einstein Telescope beam pipes

High-sensitivity optical measurements, such as those carried out in interferometric gravitational-wave detectors, are highly susceptible to stray light noise. Because of the exceptional quality of the optics employed, scattering is often dominated by residual particulate contamination. This represents a critical challenge not only for the next-generation Einstein Telescope but also for current instruments like LIGO and Virgo. It is therefore essential to identify all possible light–dust interaction mechanisms and to quantify the noise they may introduce.

In this work, we present a detailed study of particulate contamination, focusing on the beam pipes of the Einstein Telescope as a case study. We consider two main scenarios for light scattered by dust inside the beam pipes: particles deposited on the baffles and particles freely moving through the beam pipe volume under vacuum. Here we report our latest results on the latter case. We first evaluate how amplitude and phase fluctuations of the optical field, induced by falling particles crossing the arm cavity beam, translate into detector strain noise. We then perform Monte Carlo simulations to investigate the impact of different cleanliness conditions. Finally, we assess how installation procedures and standard operations on the beam pipes may contribute to dust contamination.

This study will allows us to establish upper limits on the number and size of dust particles that can be tolerated detaching from the pipe's inner surfaces, therefore setting constraints on the cleanliness of environments and installation procedures. Our results refer specifically to Einstein Telescope, but they can be extended easily to other ground-based interferometers.

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