Telefilters, telemirrors, and causality

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Mode-selective interactions are ubiquitous in quantum optics and interacting quantum field theories. Such unitaries take as input a multi-mode field but uniquely affect a single mode, compared with those orthogonal to it. Despite their wide application in theoretical and experimental physics, the temporal dimension of such interactions are typically ignored. Here, I demonstrate how the naïve treatment of a mode-selective unitaries leads to the possibility of acausal signalling, due to the tacit assumption that certain kinds of idealised measurements of quantum fields can be made. I achieve this by introducing new theoretical models for mode-selective mirrors using continuous-variable teleportation, which is able to unveil the temporal aspects of the mode propagation. The main result is that mode-selective operations must generally enact a fundamental time-delay on input modes that are delocalised in time. This result resolves Sorkin's long-standing "impossible measurement" problem in relativistic quantum field theory, and thus has significant implications for experimental quantum optics and those working in quantum causality and field theory.

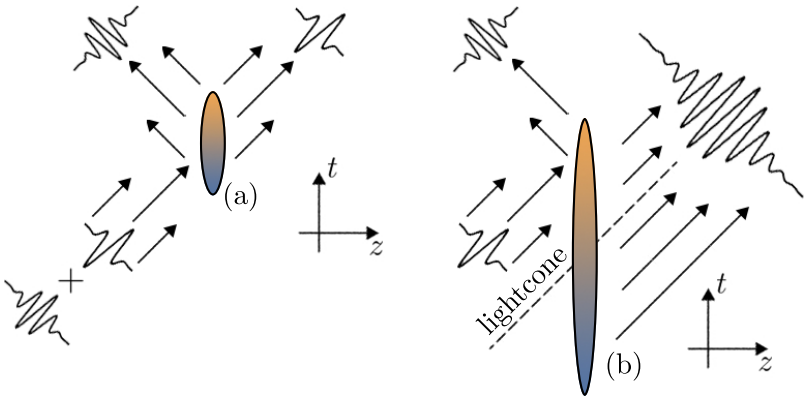

Figure 1: Schematic diagram of the acausal signalling scenario which our paper addresses. In (a), the mode propagation is manifestly causal, because the interaction and mode are short in time. In (b), acausal signalling arises when the length of the mode and interaction do not perfectly overlap.

[1] Joshua Foo, Sho Onoe, Magdalena Zych, and Timothy C. Ralph, Physical Review A 105, 3 (2021).