Exploring the role of weak measurements in dissipative quantum systems

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A quantum weak measurement is a four-step procedure that involves a target system and an ancillary meter [1]. In the initial phase, pre-selection occurs, necessitating the careful choice of the system's initial state. Proceeding to the second step, a weak measurement is performed via a unitary operator that intertwines both the ancillary meter and the system of interest. The third step encompasses a post-selection procedure applied to the system, including a projective measurement process along with subsequent filtration. Eventually, the meter wave function is readout. Within the meter's wave function, two distinct shifts come to the fore. One shift, perceptible in the position representation, is directly proportional to the real component of the weak value, expressed as $A_w = \frac{\langle\psi_f|\hat{A}|\psi_i\rangle}{\langle\psi_f|\psi_i\rangle}$. In contrast, the shift observed in the momentum representation holds a direct proportionality to the imaginary part of the weak value. It is noteworthy that the weak value emerges as a complex and unbounded entity. The phenomenon of weak measurement has garnered substantial interest due to its inherent amplification capabilities. The utilization of complex numbers in this context has further demonstrated its advantageous utility.

In the realm of quantum phenomena, genuine isolation of quantum systems remains an unattainable ideal. These systems invariably engage in interactions with their environments. The field of open quantum systems theory delves into the intricate interplay between a system of interest and its environment, elucidating how this interaction reshapes the system's dynamics.

Our investigation delves into the realm of weak measurements accompanied by dissipation, specifically exploring scenarios where dissipation takes place subsequent to the weak measurement but before the post-selection stage [2]. The procedural sequence can be succinctly outlined as follows : commencing with a pre-selection step targeting the system's initial state, followed by the application of a comprehensive unitary operator, denoted as $\hat{U} = e^{-ig\hat{A}\otimes\hat{N}}$. Subsequently, the system engages in a dissipative interplay, and after a prescribed duration τ, the post-selection process comes into play. Notably, this scheme is present in any experimental setup with a time delay between the unitary evolution and the post-selection. The time of weak measurement is assumed to be as short as dissipation is negligible.

In our exploration of the interplay between dissipation and weak values, we focus on the intriguing scenario where the dissipation time approaches infinity. For non-degenerate systems, as this dissipation time elongates, the distinctive characteristics of the weak value are significantly eroded, gradually converging towards the operator's expectation value. However, within the realm of degenerate ground state systems, a contrasting phenomenon emerges : dissipation possesses the remarkable capacity to uphold anomalous weak values, persisting even as the dissipation time extends infinitely.

Weak values can also be used at short times to extract information about the dissipative dynamics of the system, such as the dissipation rate. They can also be employed to differentiate non-Markovian from Markovian dynamics.

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[1] Yakir Aharonov, David Z Albert, and Lev Vaidman. How the result of a measurement of a component of the spin of a spin-1/2 particle can turn out to be 100. *Physical review letters*, 60(14) :1351, 1988.

[2] Lorena Ballesteros Ferraz, John Martin, and Yves Caudano. On the relevance of weak measurements in dissipative quantum systems. *arXiv preprint arXiv :2308.00722*, 2023.