Quantum tomography—characterising a quantum system by assigning it a quantum state—is an essential building block for future technologies like quantum metrology or quantum computation. Ideal quantum tomography is accurate and robust to noise, while simultaneously being quick and efficient. The standard technique used for decades, full quantum tomography (FQT), only fulfills parts of these criteria and quickly becomes unfeasible, even for medium sized systems. As the number of possible states increases, the requirements on the amount of measurements to characterise the system and the storage of the results grow with it exponentially. The very feature that gives quantum mechanics its immense possibilities, hinders our capacity to describe it. Additionally, FQT is neither robust to noise nor to experimental errors, and generally fails in the presence of these environmental perturbations unless additional resources are used at the cost of efficiency.

Self-guided quantum tomography (SGQT), as proposed by Ferrie [1], is a direct technique where the result is converging to the state itself rather than providing an estimate of its fidelity. As well as being robust and precise, this technique works quickly, autonomously, and efficiently. SGQT avoids many issues of FQT and other techniques at the expense of having to measure adaptively—the subsequent measurement settings in each iteration are chosen depending on the outcome of measurements in the previous iteration. The advantages of SGQT have been proven theoretically for general systems [1], but have been experimentally tested only in low dimensions, i.e. two qubits [2]. Here, we apply SGQT to photon-shape qudits, carrying optical angular momentum, a higher-dimensional system which naturally lends itself to SGQT.

We achieve fidelities over 99.9% for qutrits (d=3) and ququints (d=5), and 99.1% for quvigints (d=20)—the highest values ever realised for qudit pure states [3]. Fig. 1 compares the performance of the algorithm as a function of iterations in our experiment (blue) with the theoretical simulations (red) for the 3 dimensions under investigation. We show that SGQT outperforms FQT, both in terms of achievable fidelity for the same number of copies of the unknown state and overcoming errors. We demonstrate robustness against environmental sources of noise, be it statistical for low count rates or environmental through mode-dependent losses and atmospheric turbulence. We also implement an extension of the originally proposed algorithm to mixed states, maintaining its excellent performance by achieving average fidelities of 96.5% for qutrits. The technique is applicable to any higher-dimensional system, from a collection of qubits through to individual qudits, and any physical realisation, regardless of whether it is photonic, superconducting, ionic, or spin.

Fig. 1. Self-guided tomography for (a) qutrits, (b) ququints, and (c) quvigints. Theoretical model in solid red and corresponding experimental result in dashed blue. The lines are the median performance, while the shaded regions are bound by the upper and lower quartile of the infidelities, (50 ± 25)%.

References
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