Contactless nonlinear optics mediated by long-range Rydberg interactions

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In conventional nonlinear optics, linear quantum optics1 [3], 2 [4], and cavity quantum electrodynamics3 [5], 4 [6] to create effective photon–photon interactions photons must have, at one time, interacted with matter inside a common medium. In contrast, in Rydberg quantum optics5 [7], 6 [8], 7 [9], 8 [10], 9 [11], 10 [12], optical photons are coherently and reversibly mapped onto collective atomic Rydberg excitations11 [13], giving rise to dipole-mediated effective photon–photon interactions that are long range12 [14], 13 [15]. Consequently, a spatial overlap between the light modes is no longer required. We demonstrate such a contactless coupling between photons stored as collective Rydberg excitations in spatially separate optical media. The potential induced by each photon modifies the retrieval mode of its neighbour7 [9], 9 [11], 14 [16], 15 [17], leading to correlations between them. We measure these correlations as a function of interaction strength, distance and storage time, demonstrating an effective interaction between photons separated by 15 times their wavelength. Contactless effective photon–photon interactions16 [18] are relevant for scalable multichannel photonic devices15 [17], 17 [19] and the study of strongly correlated many-body dynamics using light18 [20].

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