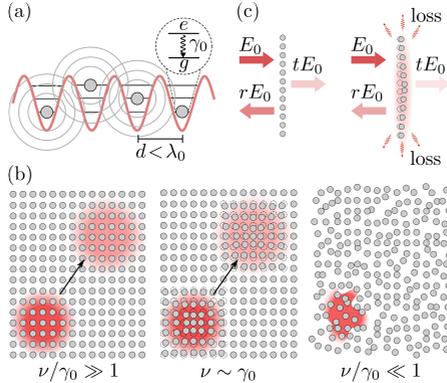


# Motion in Subwavelength Atomic Arrays: Polaron-Polaritons

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We study how atomic motion modifies the collective dipolar excitations and light–matter interactions of subwavelength atomic arrays [Fig. 1(a)]. In the Lamb–Dicke regime, we derive an effective polaron–polariton description that captures correlated spin–phonon dynamics beyond previous “fast” and “frozen” motion approaches. Using both analytical polaron theory and numerical simulations, we show that: (i) excitation transport remains surprisingly robust against motion, even at low trap frequency [Fig. 1(b)], (ii) phonon emission can strongly boost decay of subradiant states as well as enable their excitation, (iii) the detrimental impact on the reflectivity of a 2D atomic mirror can be alleviated by changing the trap frequency, which moves phononic sidebands out of resonance [Fig. 1(c)], and (iv) in the presence of atomic recoil an array still radiates directionally when it is driven close to a phononic sideband. Our findings lay the foundation for analyzing motional effects in key applications and suggest new ways to harness subradiant modes and optomechanical effects in emerging experiments.



**Fig. 1: Motional effects in subwavelength arrays.** (a) Subwavelength arrays of trapped atoms: recoil due to emission and absorption modifies the arrays’ optical response. (b) Transport of an excitation in a 2D array of atoms is robust to changes in the trap frequency. For finite trap frequency, a polaron dressed by lattice phonon propagates (center) similarly to the case of pinned atoms (left). In contrast, the frozen motion approximation could predict absence of transport. (c) Atomically thin mirrors exhibit almost perfect reflectivity when atoms are pinned (left). Recoil-induced scattering of photons into subradiant modes leads to reduced reflectivity (right). On the flip side, this same process can be used to prepare subradiant excitations in the array.

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