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Spatiotemporal moiré exciton dynamics in twisted TMDs

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Abstract

Transition metal dichalcogenides (TMDs) feature strong light-matter and Coulomb interactions, giving rise to tightly bound excitons. Stacking TMD monolayers into van der Waals heterostructures allows the existence of interlayer excitons with spatially separated charges, long lifetimes, and out-of-plane dipole moments. Recent experiments highlight phenomena such as ultrafast charge transfer, long-lived excited states, and twist-angle dependent photoluminescence (PL). Moiré potentials from lattice mismatch or twist-angle reshape the exciton landscape, promoting interaction-enhanced and correlated states. Using a microscopic exciton theory, we study the spatiotemporal dynamics of moiré excitons in TMD bilayers across momentum and real space. In the small twist angle regime, we analyze how low-energy optical excitations relax, showing that flat moiré bands and a large energy gap create a bottleneck that inhibits thermalization at low temperatures. This accounts for enhanced PL and exciton lifetimes. We further show how these effects impact real-space propagation, revealing a temperature- and angle-dependent diffusion coefficient. Our work provides microscopic insight into twist angle-dependent exciton thermalization and transport, with implications for future optoelectronic applications.