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Engineering long-range fermion-mediated interactions in cold-atom quantum simulators

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Engineering long-range interactions in cold-atom quantum simulators can lead to exotic quantum many-body behaviour, becoming and enabling tool in the simulation of relevant problems in condensed matter or quantum chemistry [1]. In addition to recent efforts with bosonic species [2,3], fermionic atoms in ultracold atomic mixtures can also act as mediators. This gives rise to long-range Ruderman-Kittel-Kasuya-Yosida–type interactions characterized by the dimensionality and density of the fermionic gas, in agreement with current experiments [4,5].

In this work, we propose several tuning knobs, accessible in current experimental platforms, that allow one to further control the range and shape of the mediated interactions, extending the existing quantum simulation toolbox [6]. In particular, we include an additional optical lattice for the fermionic mediator, as well as anisotropic traps to change its dimensionality in a continuous manner. This allows us to interpolate between power-law and exponential decays, introducing an effective cutoff for the interaction range, as well as to tune the relative interaction strengths at different distances. Finally, we show how our approach allows one to investigate frustrated regimes that were not previously accessible, where symmetry-protected topological phases as well as chiral spin liquids emerge.

[1] JAL et al., Nature 574, 215 (2019)
[2] JAL et al., Phys. Rev. Research 2, 042013 [Rapid Com.] (2020)
[3] JAL et al., Phys. Rev. A 103, 043318 (2021)
[4] DeSalvo et al., Nature 568, 61 (2019)
[5] Edri et al. Phys. Rev. Lett. 124, 163401 (2020).
[6] JAL et al., Phys. Rev. Lett. 129, 083401 (2022).

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