Interaction Range Effects and Universality in the BCS-BEC Crossover of Spin-Orbit Coupled Fermi Gases.

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We explore the evolution of a cold quantum gas of interacting fermions crossing from a Bardeen-Cooper-Schrieffer (BCS) superfluidity to a Bose-Einstein condensation (BEC) of molecular bosons in the presence of a tunable-range interaction among the fermions and of an artificial magnetic field, which can be used to simulate a pseudo-spin-orbit coupling (SOC) and to produce topological states. We find that the crossover is affected by the competition between the longer-range interaction tending to correlate the system over large distances and to favor the BCS-like state, and the SOC term tending instead to favor the BEC-like state with formation of tightly bound molecules with small size. We then calculate the critical temperature, chemical potential, and condensate fraction in different regimes for the SOC strength and for the strength and range of the atomic interactions, finding that universal behavior sets in and persists below the topological transition when the crossover is described in terms of the correlation length. We determine the shift of the topological transition due to the interactions, and argue that above the transition universality can be restored by taking into account the existence of SOC-driven bosonic molecules on the BCS side. Our results can be relevant in view of current experiments with cold atoms in optical cavities, where tunable-range effective atomic interactions can be engineered.