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Irreversible entropy transport enhanced by proximity to fermionic superfluidity

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The nature of the flow between two superfluids, as in the Josephson and fountain effects, is often understood in terms of reversible flow carried by an entropy-free, macroscopic wavefunction. While this wavefunction is responsible for many intriguing properties of superfluids and
superconductors, its interplay with excitations in non-equilibrium situations is more subtle and less understood. We observe the strong, nonlinear response of an irreversible entropy current to biases in chemical potential and temperature between two trapped and strongly interacting Fermi gases connected by a ballistic channel. The entropy current is found to be in proportion to the nonlinear particle current, which is known to be boosted by proximity to the superfluid
state reached at equilibrium. Remarkably, the advectively transported entropy per particle is extremely robust to changes in the channel's geometry and much larger than the local entropy of the equilibrium superfluid. In contrast, the timescales of advective and diffusive entropy transport vary significantly with the channel geometry, causing the system to approach a non-equilibrium steady state in the one-dimensional limit. Our observation that the nonlinear particle current carries and produces entropy demonstrates that the flow between the two traps is itself not strictly superfluid. Our counterintuitive finding is that the proximity to a superfluid phase in the channel increases the speed of irreversible entropy transport. The presented approach shines a new light on an intriguing regime of transport, but may also help uncover novel mechanisms of heat transfer that are central to future superconducting devices.

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