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# Uncovering thermodynamic origin of counterflow and coflow instabilities in miscible binary superfluids

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In this paper, we explore instabilities in binary superfluids with a nonvanishing relative superflow, particularly focusing on counterflow and coflow instabilities. We extend recent results on the thermodynamic origin of finite superflow instabilities in single-component superfluids to binary systems and derive a criterion for the onset of instability through a hydrodynamic analysis. To verify this result, we utilize both the Gross-Pitaevskii equation (GPE) for weakly interacting Bose-Einstein condensates (BEC) and a holographic binary superfluid model, which naturally incorporates strong coupling, finite temperature, and dissipation. We find that the counterflow and coflow instabilities in binary superfluids are all essentially thermodynamic. Except the one due to order competing via global thermodynamic instability, the others are caused by an eigenvalue of the free energy Hessian diverging and changing sign. We also observe that the critical velocities of these instabilities follow a general scaling law related to the interaction strength between superfluid components. The nonlinear stages of the instabilities are also studied by full time evolution, where vortex dynamics is found to play a significant role, resulting in the reduction of superfluid velocity back to a stable phase.

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