Observation of Relaxation Stages in the Decay of a Turbulent Trapped Superfluid

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The dynamics of non-equilibrium closed quantum systems and their route to thermalization are of fundamental interest to several fields, from cosmology to particle physics. However, a comprehensive description of non-equilibrium phenomena still presents a major challenge. In this work, we report the observation of distinct stages during the relaxation dynamics of the decaying turbulence regime in Bose-Einstein condensates. Our findings show a direct particle cascade from low to high momenta, a consequence of the energy injection in the system, exhibiting a characteristic universal scaling. This stage is followed by an inverse particle cascade responsible for repopulating the previously depleted condensated. By varying the excitation parameters, we explore the particle transport in these closed systems, providing insights into the relaxation stages of out-of-equilibrium quantum many-body systems.