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Scanning nano-SQUID nanoscale thermal imaging of dissipation in quantum systems

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Energy dissipation is a fundamental process governing the dynamics of physical, chemical, and biological systems. It is also one of the main characteristics distinguishing quantum and classical phenomena. In condensed matter physics, in particular, scattering mechanisms, loss of quantum information, or breakdown of topological protection are deeply rooted in the intricate details of how and where the dissipation occurs. Despite its vital importance the microscopic behavior of a system is usually not formulated in terms of dissipation because the latter is not a readily measureable quantity on the microscale. Although nanoscale thermometry is gaining much recent interest, the existing thermal imaging methods lack the necessary sensitivity and are unsuitable for low temperature operation required for study of quantum systems. In this talk we report a superconducting quantum interference nano thermometer device with sub 50 nm diameter that resides at the apex of a sharp pipette and provides scanning cryogenic thermal sensing with four orders of magnitude improved thermal sensitivity of below 1 μK/Hz1/2. The non contact non invasive thermometry allows thermal imaging of very low nanoscale energy dissipation down to the fundamental Landauer limit of 40 fW for continuous readout of a single qubit at 1 GHz at 4.2 K. These advances enable observation of dissipation due to single electron charging of individual quantum dots in carbon nanotubes and reveal a novel dissipation mechanism due to resonant localized states in hBN encapsulated graphene, opening the door to direct imaging of nanoscale dissipation processes in quantum matter.