Abstract for IAS Focused Program on Reticular Quantum Matter (Nov 30 - Dec 4, 2026)

Real-Space Imaging of Delocalized Quantum States under Conformational Disorder

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Quantum rings are paradigmatic systems in which topology enforces phase coherence along a closed path, giving rise to delocalized eigenstates and interference phenomena. Molecular nanorings push this concept to its ultimate limit: a single, finite π-conjugated object hosting coherent quantum states. Yet how molecular geometry reshapes these states at the single-molecule level has remained experimentally unresolved. Here we directly image quantum-ring eigenstates in individual 12-porphyrin nanorings adsorbed on graphene using low-temperature scanning tunneling microscopy and spectroscopy with submolecular resolution. Discrete resonances emerge within a ~2 eV gap, and conductance maps reveal states delocalized around the entire molecular circumference. Strikingly, while resonance energies are reproducible, their real-space distribution varies from ring to ring at identical energies. Molecular dynamics simulations show that adsorption stabilizes distinct low-energy conformations, and a minimal tight-binding Hamiltonian with geometry-dependent nearest-neighbor coupling captures these conformations and reproduces the observed conductance patterns of the HOMO/LUMO manifold. These single-molecule measurements demonstrate that coherent quantum-ring states survive conformational variability and that geometry-controlled hopping governs their spatial structure.

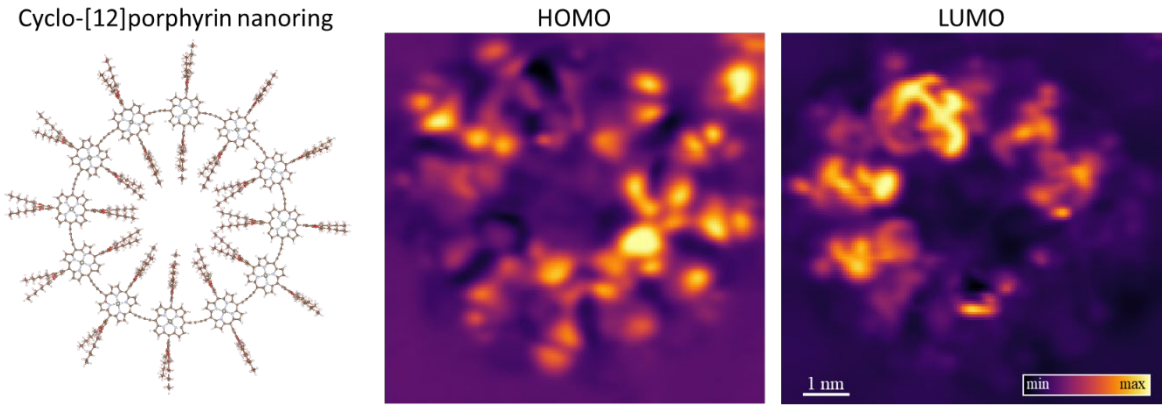


Figure. Chemical structure of the butadiyne-linked 12-porphyrin nanoring (cyclo-[12]porphyrin) and representative real-space maps of the frontier molecular orbitals (HOMO and LUMO) revealing delocalized quantum states extending around the full ring with submolecular contrast on individual porphyrins.