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Topological Kondo Ground State in Graphene[1]

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Dirac electrons in graphene comprise two-component wavefunctions and quantum symmetries intertwining pseudospin, chirality, and Berry's phase, all ultimately stemming from a node or topological degeneracy in the spectrum known as the Dirac point. Graphene represents one prototype example of a larger class of nodal metals in which a relativistic spectrum causes the density of states to vanish linearly. Based on the unique electronic structure of such systems, a large body of theoretical work has highlighted the propensity for Dirac electrons to condense in strongly correlated ground states when additionally coupled to the real spin degree of freedom. We report the observation of one of these elusive ground states, realized in graphene via unconventional Kondo screening of individual atomic spins by massless Dirac fermions. Low-temperature scanning tunneling microscopy reveals the emergence of a new energy scale and a striking bimodal Kondo resonance localized around magnetic atoms placed on a clean graphene monolayer. Quasiparticle interference maps and concomitant spectroscopy in a high magnetic field demonstrate the spin origin of the associated ground states, and their direct link to local conservation or breaking of effective time-reversal symmetry in the underlying Dirac Hamiltonian. We find these novel spin states to be topologically controlled by Berry phase interference; in the most exotic manifestation, we show experimental evidence for two electron flavors—decoupled in momentum space by a π Berry phase shift cancellation—participating in a chiral two-channel Kondo effect. We link these results to a new platform we have developed for the study of topological phases, artificial graphene assembled by atomic manipulation.

[1]This work performed in collaboration with L. S. Mattos, C. R. Moon, M. W. Sprinkle, C. Berger, K. Sengupta, A. V. Balatsky, W. A. de Heer, K. K. Gomes, W. Ko, W. Mar. We acknowledge support from DOE and NSF.