**Dirac Materials**

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**Scientific Thrust Area**: Theory and Modeling of Nanoscale Phenomena

**Projects:** Controlling the Kondo Effect in Graphene (H. Manoharan); Controlling Electron and Phonon Interactions in Graphene (M. Crommie)

**Research Achievement:**
Recently a new single layer material -- graphene has been discovered.[1] This is a material where Dirac points in the fermionic spectrum lead to a very unusual transport properties and other electronic signatures like impurity states.[2,3] We will argue that these properties are not unique to graphene and in fact are a direct consequence of Dirac spectrum in fermionic excitation sector. We point strong similarities with d-wave superconductors,[4] superfluid 3He, p-wave superconductors and with other materials exhibiting Dirac electronic spectrum and offer a unifying perspective on the discussion about nanoscale electronics in these materials. We argue that discovery of graphene signifies the emergence of a new class of materials, that we call Dirac Materials, the class where nontrivial properties emerge as a direct consequence of Dirac spectrum of excitations.

In recent work in CINT in collaboration with users from Stanford, we have addressed the local electronic properties of graphene such as impurity states,[2,3] Kondo effect,[5] and inelastic electron tunneling spectroscopy (IETS) in graphene [6] (UC Berkeley user project).

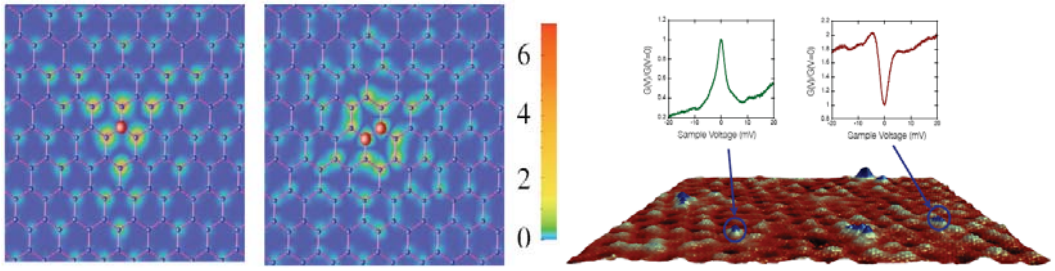


Fig.1. Right panel:Impurity induced modifications of Local Density of States in graphene. [2,3] Left panel: Local Density of states near Co impurity atom on graphene, Kondo peak and dip are observed, depending on position of an atom.[5]

**Future Work:** We plan to develop microscopic theory of Kondo effect using realistic band structure calculations. We plan to further develop theory of Inelastic Electron Tunneling Spectrosopy (IETS) in graphene.

**References:**


[1] K. S. Novoselov, A. K. Geim, S. V. Morozov, D. Jiang, Y. Zhang, S. V. Dubonos, I. V. Grigorieva, and A. A. Firsov, Science **306,** 666 (2004).

[2] T. O. Wehling, A. V. Balatsky, M. I. Katsnelson, A. I. Lichtenstein, K Scharnberg, R. Wiesendanger, Phys. Rev. B **75**, 125425 (2007).

[3] Hari P. Dahal, A. V. Balatsky, Jian-Xin Zhu, Phys. Rev. B **77,** 115114 (2008).

[4] A. V. Balatsky, I. Vekhter, J. X. Zhu, Rev. Mod. Phys. **78**, 373 (2006).

[5] Laila Mattos, and Hari Manoharan, (unpublished).

[6] T. Wehling, et. al., Phys. Rev. Lett. **101**, 21608, (2008).


**Publications:**


1. T. O. Wehling, A. V. Balatsky, M. I. Katsnelson, A. I. Lichtenstein, K Scharnberg, R. Wiesendanger, Phys. Rev. B **75**, 125425 (2007).
2. Hari P. Dahal, A. V. Balatsky, Jian-Xin Zhu, Phys. Rev. B **77,** 115114 (2008).
3. A. V. Balatsky, I. Vekhter, J. X. Zhu, Rev. Mod. Phys. **78**, 373 (2006)
4. Laila Mattos, and Hari Manoharan, (in preparation).
5. T. Wehling, et. al., Phys. Rev. Lett. **101**, 21608, (2008).