Igor Herbut: research accomplishments

1) In the general field of superconductivity

a) The exact result for the anomalous dimension of the gauge field at the superconducting, or Higgs, phase transition (I. H. and Z. Tesanovic**,** *Critical fluctuations in superconductors and magnetic field penetration depth*, Phys. Rev. Lett. **76**, 4588 (1996))

The main result of this work has been confirmed by several large-scale Monte Carlo calculations (S. Teitel, A. Sudbo), and has found numerous applications in related problems. It is probably fair to say that by now it has become common knowledge in the field of superconductivity and critical phenomena.

b) The elucidation of the nature of the superconducting quantum critical point in presence of pair-breaking disorder (I. H., *Zero temperature d-wave superconducting phase transition,* Phys. Rev. Lett. **85,** 1532 (2000))

The Ginzburg-Landau-Wilson theory of disordered superconductors derived in this paper has been used by many researchers (S. Sachdev, T. Vojta), and has been rederived (T. Vojta) and rediscovered (V. Galitski) several times since.

2) In the field of high-temperature superconductivity

a) The discovery of hidden "chiral" symmetry of d-wave superconductors, and of the concomitant connection to antiferromagnetism (I. H., *Antiferromagnetism from phase disordering of a d-wave superconductor,* Phys. Rev. Lett. **88**, 047006 (2002), I. H., *QED3 theory of underdoped high temperature superconductors,* Phys. Rev. B **66**, 094504 (2002))

These papers derived the three dimensional QED as the effective theory of underdoped cuprates, following the suggestion of Franz and Tesanovic. The identification of chiral symmetry breaking with the antiferromagnetic insulator, in particular, has prompted numerous large-scale numerical lattice calculations (J. Kogut, S. Hands), and was a forerunner of several later developments in the field of strong correlations.

b) Proposed mechanism for permanent confinement of spinons in compact gauge theories of t-J-like models (I. H. and B. Seradjeh, *Permanent confinement in the compact QED3 with fermionic matter,* Phys. Rev. Lett. **91**, 171601 (2003))

The work on confinement provided a fresh look and revived the interest in this classic problem and has stirred considerable controversy with other theorists in the field. Very recent large-scale lattice calculations on compact QED3 (W. Armour et al, arXiv:1105.3120) lend independent support to some of our results.

3) Disordered systems

a) Dual picture of supeconductor-insulator transition in thin films, and the formulation of the new epsilon-expansion around one dimension (I. H., *Finite temperature transport at the superconductor-insulator transition in disordered systems*, Phys. Rev. Lett. **81**, 3916 (1998); I. H., *Critical behavior at superconductor-insulator phase transitions near one dimension*, Physical Review B **58**, 971 (1998))

b) Independent proposal of the temperature and spin-polarization dependent screening mechanism for the observed metal-insulator transition in two dimensions (I. H., *The effect of parallel magnetic field on the Boltzmann conductivity and the Hall coefficient of a disordered two dimensional Fermi liquid*, Phys. Rev. B **63,** 113102 (2001))

This simple theory of the apparent metal-insulator transition in two dimensions, independently put forward by Dolgopolov and Gold in Russia and Das Sarma in US, has been frequently used and cited by the field's practitioners, and is also known as the "temperature-dependent screening mechanism".

4) Graphene

a) The formulation of the field theory for the Hubbard model on honeycomb lattice, and the elucidation of the Mott transitions in graphene (I. H., *Interactions and phase transitions on graphene's honeycomb lattice,* Phys. Rev. Lett. **97**, 146401 (2006), I. H., V. Juricic, and B. Roy, *Theory of interacting electrons on honeycomb lattice,* Physical Review B **79,** 085116 (2009), I. H, V. Juricic, and O. Vafek, *Relativistic Mott criticality in graphene,* Physical Review B **80**, 075432 (2009), V. Juricic, I. H., G. Semenoff, *Coulomb interaction at the metal-insulator critical point in graphene,* Physical Review B **80,** 081405(R) (2009))

In the first paper in the series above, I showed that the field theory of interacting graphene has the Gross-Neveu form, and that it describes the transitions from the semimetal to charge-density wave or spin-density-wave insulators. I also determined the critical exponents in the limit of large number of Dirac points. This paper has become a standard reference on the problem of interacting electrons in graphene. In the later series of papers we have further developed the field theory, and in particular devised a new perturbative approach to the Mott criticality in graphene, by identifying and exploiting the upper critical dimension in the problem. We have also studied the subtle effects of long-range Coulomb interaction on the critical behavior. Our results have prompted large-scale Monte Carlo calculations (Drut and Lahde, Kogut, Hands) and numerous other theoretical studies of the problem. Our general approach has also found a recent important application in the related problem of instabilities of the bilayer graphene (Levitov, Vafek).

b) Theory of interaction-induced quantum Hall effect near the Dirac point (I. H., *Theory of integer quantum Hall effect in graphene,* Physical Review B **75**, 165411 (2007), I. H. *SO(3) symmetry between Neel and ferromagnetic order parameters for graphene in magnetic field,* Physical Review B **76**, 085432 (2007))

I proposed early on that the observed Hall effects in graphene at filling factors zero and one are manifestations of magnetically induced instabilities towards, most likely, a spin density wave phase. This conclusion has recently received support from detailed lattice computations (Jung and MacDonald), but experimentally the question of the ground state at half filling is still an open problem.

c) Discovery of the line of critical points in interacting disordered graphene Hamiltonian and the determination of the interaction correction to universal conductivity (I. H., V. Juricic, and O. Vafek, *Coulomb interactions, ripples, and the minimal conductivity of graphene,* Phys. Rev. Lett. **100**, 046403 (2008))

We have found that the combined effect of ripples and Coulomb interactions in graphene is a new line of fixed points, along which the conductivity, for example, varies continuously. In the process we solved the problem of purely interaction effect on the optical conductivity in graphene, which is the leading, logarithmically irrelevant, but a sizable correction. Our paper has initiated a debate about the actual size of the interaction correction to conductivity (Mishchenko, Schmalian). The issue is hopefully laid to rest by our recent long paper on the subject: V. Juricic et al, Phys. Rev. B **82**, 235402 (2010).