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14. ABSTRACT
This report summarizes the progress made under the STIR grant. We completed the exploratory phase of a newly developed idea, which is to study novel electronic phases at the interfaces of heavy fermion heterostructures. The key physics is that the strong and tunable spin-orbit coupling (SOC) may induce new electronic phases that are difficult to realize in bulk materials. With the support of this STIR grant, we have a) completed a theoretical study, which illustrates that the tuning of SOC gives rise to transitions between quantum phases in a Kondo insulator

15. SUBJECT TERMS
2D heavy fermions, quantum criticality, spin-orbit coupling, global phase diagram

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UU	UU	UU	UU		19b. TELEPHONE NUMBER 713-348-5204

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Report Title

Final Report: Spin-Orbit Coupling and Novel Electronic States at the Interfaces of Heavy Fermion Materials

ABSTRACT

This report summarizes the progress made under the STIR grant. We completed the exploratory phase of a newly developed idea, which is to study novel electronic phases at the interfaces of heavy fermion heterostructures. The key physics is that the strong and tunable spin-orbit coupling (SOC) may induce new electronic phases that are difficult to realize in bulk materials. With the support of this STIR grant, we have a) completed a theoretical study, which illustrates that the tuning of SOC gives rise to transitions between quantum phases in a Kondo insulator system; and, equally important, b) motivated experimentalists to embark on the fabrication of Kondo insulator heterostructures and the exploration of quantum phase transitions induced by the interplay among a tunable SOC, Kondo coupling, and magnetism associated with RKKY interactions. As such, our work has moved forward with exploring a promising new parameter regime in the correlated-electron “global” phase diagram of heavy fermion materials and, in addition, paving the way for interactions between the heavy fermion and correlated oxide heterostructure communities.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

--"Local Perspective on Non-Fermi Liquid, Quantum Criticality, and Bad Metals", Aspen Center for Physics 2014 Winter Conference on Condensed Matter--Beyond Quasiparticles: New Paradigms for Quantum Fluids, Aspen, Colorado, Jan 12-18, 2014.

--"Quantum Criticality, Emergent Magnetic Phases and Superconductivity", DOE-CAS Heavy-Fermion Workshop, Los Alamos National Lab., New Mexico, Nov. 18-19, 2013.

--"Quantum Phase Transitions in Heavy Fermion Metals and Kondo Insulators", Conference on Quantum Criticality: Experiment and Theory, Freudenstadt-Lauterbad, Germany, Sept. 15-19, 2013.

--"Superconductivity on the Border of Magnetism: Heavy Fermions and Iron Pnictides", NORDITA Workshop on Superconductivity: the Second Century, Stockholm, Sweden, Aug. 20, 2013.

--"Quantum Criticality, Magnetic Frustration and Emergent Phases in Heavy Fermion Metals", International Conference on Strongly Correlated Electron SCES-2013, Tokyo, Japan, Aug. 5-9, 2013.

--"Quantum Phase Transitions in Heavy Fermion Metals and Kondo Insulators", Aspen Center for Physics Summer Workshop -- Disorder, Dynamics, Frustration and Topology in Quantum Condensed Matter, Aspen, CO, July 9, 2013.

Number of Presentations: 6.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
02/22/2016	1.00	X.-Y. Feng, J. Dai, C.-H. Chung, and Qimiao Si. Competing topological and Kondo insulator phases on a honeycomb lattice, Phys. Rev. Lett. 111, 016402 (2013). (07 2013)

TOTAL: **1**

Number of Manuscripts:

Books

Received	Book

TOTAL:

Received	Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

Humboldt Prize (Alexander von Humboldt foundation)
with the Research Award, I spent part of the summer 2013 at Karlsruhe Institute of Technology, working in part on heavy fermion quantum criticality.

Graduate Students

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Wenxin Ding	0.50
FTE Equivalent:	**0.50**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Qimiao Si	0.08	
FTE Equivalent:	**0.08**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

Under my STIR grant, I have completed the initial theoretical work along this new direction [1]. In this theoretical work, we introduced an SOC term in a Kondo lattice model, which contains both itinerant electrons and local magnetic moments, in two dimensions (2D). I demonstrated a new and intriguing interplay between SOC and Kondo entanglement in the 2D limit induces a quantum phase transition, with the SOC introducing both a competition with the Kondo effect and non-trivial topological in the electronic structure. Specifically, the new quantum phase transition is between a Kondo-destroyed topological insulator phase and a Kondo insulator phase. More generally, our results suggest that heavy-fermion systems contain a new parameter regime that features a competition among topological, Kondo coherent and magnetic states.

Based on my work supported by the grant, I also interacted with experimental groups to open up a completely new direction of experimental studies on the 2D electrons of heavy-fermion heterostructures. In particular, I interacted with the group S. Buehler-Paschen of Vienna University of Technology, regarding the molecular-beam-epitaxial (MBE) growth of Kondo insulators and heavy fermion metals. We identified several combinations of heavy fermion materials for MBE growth, including that of Ce3Bi4Pt3 and Ce3Bi4Pd3. In anticipation of a close theory-experimental collaboration along this new direction, I considered the physical properties that would be measurable in such 2D electron systems, particularly those that could signify the emergence of novel phases. Examples include the normal Hall effect and quantum oscillations, which probe the characteristics of the Fermi surface, and the intrisinc anomalous Hall effect, which probes the Berry curvature of the electronic states.

The above lines of research led to a successful submission of a proposal for a regular grant to ARO along the direction opened up by the STIR grant.

[1] X-Y Feng, J. Dai, C-H. Chung and Q. Si, “Competing topological and Kondo insulator phases on a honeycomb lattice”, Phys. Rev. Lett. 111, 016402 (2013).

Technology Transfer