Creating, manipulating and imaging complex quantum states in a single atom

**Name/Contact of Project:** Poul Jessen, Ph.D.

**Project Description:** Quantum mechanics has been the "theory of everything" for about a century, accounting for the behavior of light and matter at all scales. It was originally developed to explain the structure of the atom, but quantum mechanics has also been the key to modeling more complex systems such as molecules and solids, and has allowed us to understand phenomena ranging from superconductivity to photosynthesis. As if such tremendous accomplishments were not enough, modern quantum physicists are looking to a new challenge: how do we make quantum systems behave the way we want, rather than having them do what comes naturally to them. This has opened up an entirely new field of "quantum engineering, aimed at developing methods to manipulate individual quantum systems and using them as building blocks for new kinds of devices. In theory such quantum devices have the potential to revolutionize computer, communication and sensor technology.

Over the past few years the Jessen group have developed techniques for very precise control and imaging of quantum states in the laboratory. Our experimental testbed consists of individual ultracold atoms controlled by radio-frequency (rf), microwave (µw) and optical fields, but the methods are not system specific and can be applied across a wide range of physical platforms. One important challenge is the design and preparation of complex quantum states that can serve as inputs to a quantum simulator. In this project the REU student will use Matlab to design quantum states with specified properties, and then use numerical optimization to find rf and µw control fields that produce these states. He/she will then work with a mentor to implement the computer generated "recipes" in in the laboratory, and use quantum tomography to "image" the resulting quantum state.

**Required Skills:**
- Basic knowledge of quantum mechanics, e. g., successful completion of a one semester course in introductory quantum mechanics.
- Familiarity with Matlab, and some experience applying it to numerical problem solving.

**Ideal Skills:**
- Advanced knowledge of quantum mechanics approaching the graduate level, with some exposure to atomic physics, optical physics and/or quantum information.
- Expert knowledge of Matlab and its use in numerical modeling and data analysis
- Laboratory experience with lasers, analog electronics, optics and ultracold atoms