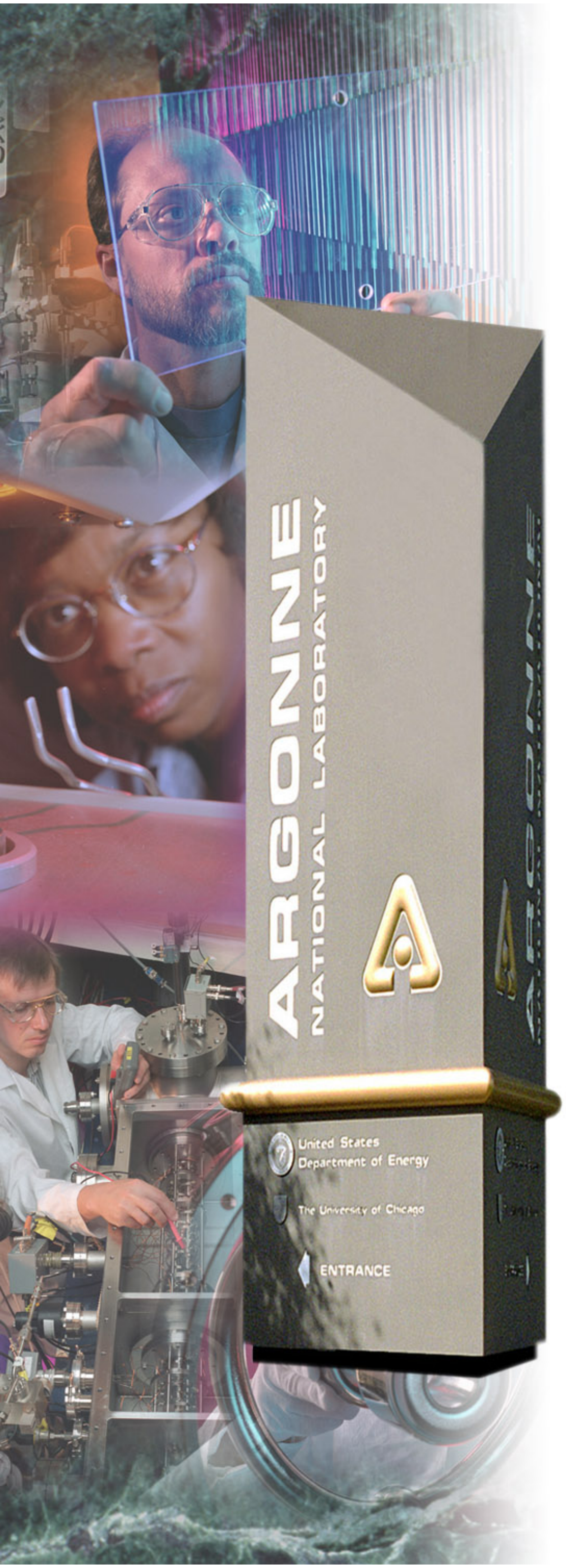


# The Grand Challenges Ahead

*Presented by*

***Sam Bader***

*at the*

International Argonne Fall Workshop on Nanophysics V:

Nanoscale Superconductivity and Magnetism

*November 14, 2005*

World Year of PHYSICS 2005

***Argonne National Laboratory***

Office of Science
U.S. Department of Energy

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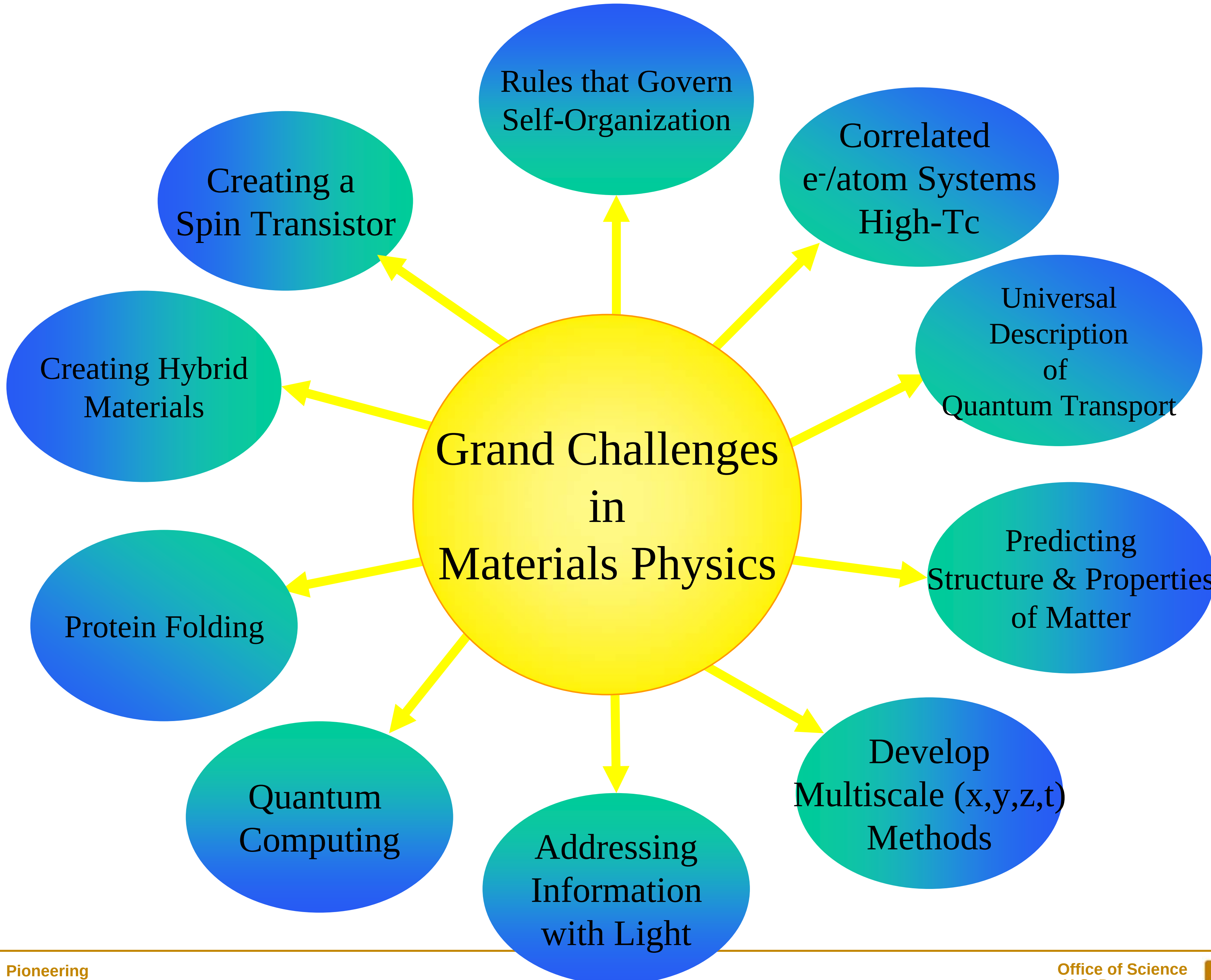
# Welcome


Rules that Govern Self-Organization
Creating a Spin Transistor
Correlated e⁻/atom Systems High-Tc
Universal Description of Quantum Transport
Creating Hybrid Materials
Grand Challenges in Materials Physics
Predicting Structure & Properties of Matter
Protein Folding
Develop Multiscale (x,y,z,t) Methods
Quantum Computing
Addressing Information with Light

# Great Questions and Challenges

## Proposed by Tony Leggett

1. Why do all amorphous materials behave in the same way below 1 K?
2. Can we build a robust room-temperature superconductor? How?
3. Does quantum mechanics fail at some level of size/complexity/organization?
4. If no to the last, are there any a prior limits on the degree of coherence we can attain with macroscopic degrees of freedom (e.g., SQUIDs)?
5. Is there a universal origin to 1/f noise?
6. Does nature exploit the phenomenon of entanglement, e.g., in biological processes?
7. Are there completely new types of order to be found in condensed-matter systems?

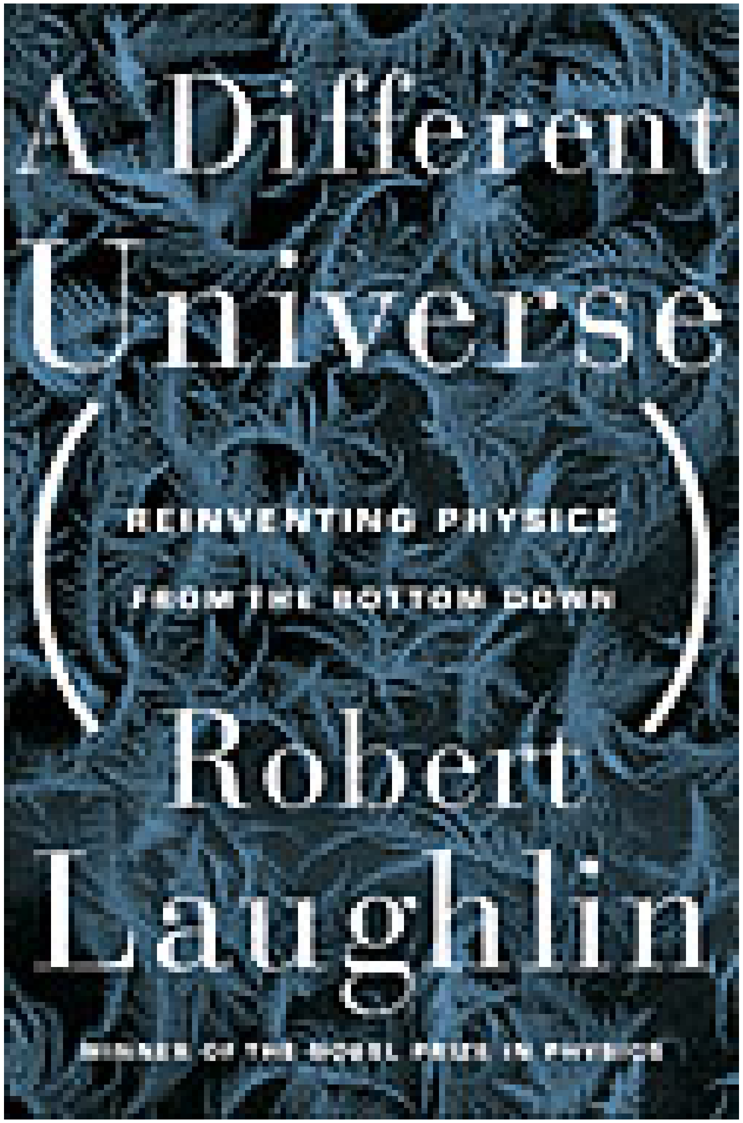
# Questions from a Workshop of the Institute for Complex Adaptive Matter

1. What fundamentally new classes of matter await discovery?
2. What is the origin of high temperature superconductivity?
3. What is the nature of strange metals?
4. What new principles of the cosmos can be discovered from a study of condensed matter?
5. Is quantum computation feasible?
6. Why don't glasses flow like liquids?
7. What principles govern the organization of matter away from equilibrium?
8. Can statistical mechanics be applied to a system as complex as the living cell?
9. How do singularities form in collective matter and in space-time?
10. What principles govern the flow of granular materials?
11. What are the physical principles of biological self-organization?

# Preliminary Questions Developed by DOE's BESAC

1. What are the fundamental phases of matter (no longer just solid, liquid, and gas, but also liquid crystals [many phases], plasmas, BEC, superfluidity, superconductivity, ferromagnetic/paramagnetic materials, and more); can we understand, model, predict, and harness phase transitions; and what are the implications for other fields of science?
2. Why does the quasiparticle construct – the "standard model" of condensed matter physics – fail for large classes of materials, and what is beyond the standard model?
3. What is the nature of the chemical bond (revisited)? How do the strong and weak interatomic forces, acting in concert, guide reactivity and molecular rearrangements/folding?
4. How do electrons, atoms, molecules, cells, and organisms naturally communicate between and among one another, and over what distances do communications occur? Can we predict how communication affects the evolution of things on all scales? Can we harness the properties of elementary particles, atoms, and molecules to create fundamentally new ways to store, manipulate, and transmit information?
5. Are there as-yet-undiscovered organizing principles at the nanoscopic and mesoscopic scales, intermediate between atomic and macroscopic dimensions?
6. To what extent are reductionist approaches to phenomena limited, and where limits exist, what is to be done? Can we predict and control emergent properties?
7. What are the molecular origins of the evolution of life? Can this understanding guide future synthesis paths and functional synthetic diversity?

# Can we agree on what’s important?




**“The concept of emergence, touted as a revolutionary new paradigm, turns out at the end of the day to be little more than a catchall label for a miscellaneous collections of things we all understood perfectly well already. As an explanatory or even heuristic principle in its own right, ‘emergence’ is completely vacuous.”**

**-Tony Leggett**

***Physics Today*, 10/05**

# Welcome