RESEARCH SUMMARIES

(Contracts/Grants Administered)
July 2003 – June 2004

Guenter Ahlers **06/01/87-01/14/04** **$2,238,854**
Department of Energy, DE-FG03-87ER13738

Bifurcations and Patterns in Nonlinear Dissipative Systems

Pattern formation in non-linear dissipative systems is explored by subjecting a variety of systems to a thermal gradient. Compressed gases, binary mixtures and nematic liquid crystals heated from below are studied in and around the transition to convection. Understanding of instabilities in complex fluids is sought for.

Guenter Ahlers **09/15/03-3/14/07** **$610,486**
Department of Energy, DE-FG02-03ER46080

Heat Transport by Turbulent Rayleigh-Benard Convection

We hope to complete the construction of a turbulence facility which can accommodate large convection cells with a diameter of 0.5m. Initially we will operate this system using water, methanol, ethanol, and iso-propanol as the convecting fluids. This work spans the Prandtl number range from σ = 4 to 34 and the Rayleigh number range up to 10^{13}. The system is designed so that it can be used later in our program with gasses at pressures up to 10 bars. Using SF_6, we expect to reach Rayleigh numbers up to 2 x 10^{13} for σ = 0.8. Much of this parameter range is as yet unexplored by previous experiments. Some of it will overlap with results from experiments using cryogenic helium and thus will help to elucidate interesting questions provoked by that work.

Guenter Ahlers **01/30/01-09/30/04** **$247,313**
National Aeronautics and Space Administration, NAG8-1757

The Superfluid Transition of ^{4}He Under Unusual Conditions

High-Resolution Thermometers (HRTs) have been in use since the Lambda Point Experiment (LPE) of Lipa et al., but those early devices were inconvenient because they were rather large and needed an external solenoid to provide a magnetic field. We carried out a detailed design, a theoretical analysis, and experimental tests of a miniaturized HRT for use in the temperature range from 1.6 to 5 K. The device uses a dc-SQUID magnetometer to determine the change in magnetization with temperature of a paramagnetic salt in a magnetic field. The field is provided by a small permanent magnet attached to the thermometer. Measurements of the sensitivity agree well with the theoretical analysis. Near 2.17 K (the superfluid transition of ^{4}He at saturated vapor pressure) the thermometer has a specific sensitivity of 4000 f0 / K Gauss. There it achieves a temperature resolution better than 10^9 K when it is charged with a field of about 300 Gauss. At 4.2 K, the specific sensitivity is smaller by a factor of 50, but still allows temperature measurements with a resolution better than 10^7 K. Near 2.17 K, drifts of the device are below the level of 10^{13} K/s. The thermometer has a small mass of about 7 g (excluding the magnet), and thus the advantage of relatively small cosmic radiation heating during microgravity experiments in Earth orbit.

Guenter Ahlers **03/26/03-1/31/07** **$718,000**
National Aeronautics and Space Administration, NAG3-2872

Boundary Effects on Transport Properties and Dynamic Finite-Size Scaling Near the Superfluid-Transition Line of ^{4}He

An important, as yet unresolved, issue in condensed-matter physics is the nature of the boundary conditions which are appropriate to describe the interface between a liquid and a solid. The primary objective of this continuation proposal is the continuation of measurement of finite-size effects on the thermal conductivity lambda near the superfluid transition of ^{4}He confined in a cylindrical geometry.

Guenter Ahlers **05/01/03-04/30/05** **$256,020**
National Aeronautics and Space Administration, NAG3-2903

The Superfluid Transition of ^{4}He Under Unusual Conditions

This award continues the work on the superfluid transition in a heat current. With previous support from NASA, we have begun to extend the studies to pressures greater than saturated vapor pressure. We now propose to study the properties of this system in the immediate vicinity of the phase transition in greater detail, and to extend the pressure range of our measurements. This work has a direct bearing on the proposed flight experiment DYNAMX, which will probe similar phenomenon in smaller heat currents. We expect this work to yield new fundamental scientific results and to be relevant to the detailed choice of parameter values for the DYNAMX flight experiment.

Guenter Ahlers **05/15/00-04/30/04** **$450,000**
National Science Foundation, DMR-0071328

Fluctuations Near Bifurcations in Spatially Extended Systems Far From Equilibrium

Over two decades ago it was predicted that nonlinear interactions between thermally driven fluctuations in dissipative non-linear non-equilibrium systems lead to deviations from mean-field theory, i.e. to genuine "CRITICAL PHENOMENA". We observed and studied quantitatively such deviations as a supercritical primary bifurcation is approached. We measured the mean-square director-angle fluctuations áq2ñ below the bifurcation to electroconvection of a nematic liquid crystal. For emf º V2/V2 - 1 -0.1 (V is the applied voltage) we find áq2ñ µ |emf|-g with g given by linear theory (LT). Closer to the bifurcation there are deviations from LT with a smaller g and with Vc2 >. This constitutes the first observation of “CRITICAL PHENOMENA” near bifurcations in nonequilibrium systems. Detailed analysis of the structure factor of the fluctuations reveals anomalous (i.e. non-LT) behavior for the direction and the modulus of the wavevector of the fluctuating rolls, as well as for the spatial correlation lengths.

Guenter Ahlers **09/01/02-10/01/03** **$3,309**
UC Humanitas Research Institute, SB030024

Thermally Driven Fluctuations Below the Onset of Electroconvection

Initiates a collaboration to study, theoretically and experimentally, the nonequilibrium fluctuations below the threshold of electroconvection. The UC team will perform experiments using the quantitative shadowgraph technique, to measure the structure factor of the nematics in the homogeneous quiescent state. The laboratory of Prof. Ahlers at Santa Barbara has all the equipment required for such a task. The Universidad Complutense de Madrid team will develop the theory required for the interpretation of the experimental data, taking advantage of the experience acquired during these last years in the study of fluctuations in the Rayleigh-Benard problem.

S. James Allen **08/15/00-07/31/03** **$182,290**

Arthur Gossard **UC Matching Funds** **$ 78,125**
Elizabeth Gwinn
Mark Rodwell
National Science Foundation, DMR-0076296

Development of a Laser Driven Terahertz System to Study Materials and Devices, and Student Training

A Laser Driven Terahertz System will provide new research instrumentation for high-resolution linear terahertz spectroscopy of materials, material structures, and devices. The research and development of this new instrument will provide interdisciplinary education and training for the post-doctoral researcher committed to the project and to graduate students and undergraduate researchers who will use the instrument in physics, material science and solid state electronics.

S. James Allen **07/01/03-07/31/03** **$10,532**
Passport Systems, SB040002

C.W. Test of the UCSB Free Electron Laser Electron Beam

David Awschalom **12/01/00-11/30/05** **$281,653**
Cornell University, 38996-6462

Ballistic Electron Microscopy Studies of Hot Electron Spin Injections into Semiconductors

This award focuses on growth and provision of semiconductor materials. We will also collaborate with Cornell University in the optical detection of spin injection in semiconductors and in the development of devices based on this phenomenon.

David Awschalom **05/01/01-04/30/06** **$700,000**
Cornell University, 39508-6587

Spin Interactions and Spin Dynamics in Electronic Nanostructures

This award proposes a multidisciplinary, multi-university research program that draws on leading experts and unique research facilities from across the nation, and which has as its organizing theme the study, understanding and control, at the nanoscale, of the spin properties of electronic systems of very substantial technological potential. This aggressive research program examines nanostructures fabricated by both bottom-up and top-down techniques. In the former case, spin systems are assembled spin-by-spin by both atomic manipulation and advanced materials processing techniques, and studied by innovative scanned probe measurement technologies. In the latter, the most advanced methods of nano-fabrication are employed to produce functional, nanostructured spin devices that can be electronically addressed and studied by highly sensitive tunneling and direct electrical transport spectroscopies, and investigated in detail by advanced scanned electrical, optical and mechanical resonance probe instrumentation. The program objectives are to substantially advance our understanding and control of spin phenomena at the nanoscale, to develop new and improved experimental approaches for the measurement and characterization of spin systems with sensitivity approaching the detection of an individual spin, and to explore and develop new approaches that will enable the study, manipulation and reversible modification of spin-interactions and dynamic spin phenomena in nanoscale systems.

David Awschalom **11/01/98-10/30/04** **$840,000**
Navy, N00014-99-1-0077

Optically-Driven Spin Transport in Magneto-Electronic Nanostructures

This award describes efforts to develop a fundamental basis for a semiconductor-based "spintronics" technology that builds a nexus between semiconductor quantum electronics and contemporary magnetics. Such a combined technology could offer a potentially powerful route for integrating spin-dependent logic with high-density storage, as well as for developing truly quantum logic devices that exploit the full quantum mechanical functionality of confined charge carriers. The principal focus of the project is to elucidate the basic aspects of spin injection and propagation in different classes of magneto-electronic systems, ranging from conventional semiconductor quantum structures to hybrid ferromagnet/semiconductor bipolar devices and spanning dimensions from the macroscopic to the mescoscopic to the nanoscale. The project involves a close collaboration between the Principal Investigators (Prof. D. D. Awschalom at the University of California, Santa Barbara and Prof. N. Samarth at the Pennsylvania State University) and employs a synergistic approach in which state-of-the-art materials design/processing/characterization are combined with advanced physics measurement techniques such as femtosecond resolved magneto-optical spectroscopies. The understanding of the fundamental concepts addressed in this proposal will have an important impact on efforts at coherent control of electronics in semiconductor quantum structures for use in next generation ultrahigh speed quantum computing technologies.

David Awschalom	**09/30/88-09/29/04**	**$4,100,000**
S. James Allen	**UC Matching Funds**	**$292,500**
Andrew Cleland		
Arthur Gossard		
Elisabeth Gwinn		
Evelyn Hu		
Herbert Kroemer		
Pierre Petroff		
Jim Speck		

Navy, N00014-99-1-1096

Program on Spintronics: Electrically and Photonically Controlled Magnetisms on Semiconductors

A concerted, multi-institution research award to build a national materials and device framework for a "spintronics" technology that relies on the electronics and photonic manipulation of electron spin in semiconductors. The goal of the program is to demonstrate proof-of-concept spintronic devices such as gated spin field effect transistors, spin diodes/filters and non-volatile semiconductor-based MRAMs. The integration of such discrete devices would eventually pave the way for a multifunctional spintronic chip with both logic and memory capability. The prototype device schemes described in the award will be derived from magnetically-active semiconductors in which spin effects are large at least at cryo-cooler (and possibly ambient) temperatures. The principal magnetic materials of interest that form the foundations for these spintronic components include the recently discovered III-V ferromagnetic semiconductors such as (Ga,Mn)As, metallic (e.g. Fe, GaMn, MnAs, MnSb) and half-metallic (e.g.Heusler alloy) ferromagnets, rare-earth chalcogenides (e.g. EuS) and also insulating antiferromagnets (e.g. MnSe). In addition, n-doped (non-magnetic) III-V, III-VII and II-VI semiconductors--wherein recent experiments have shown relatively long spin dephasing times at elevated temperatures--will also be employed as conduits for optically-injected coherent spin transport. We emphasize that the successful implementation of such an ambitious program relies on the tight networking of an extensive materials growth/processing effort with leading edge Measurement and device expertise, as well as substantial theoretical support. The program is centered at UCSB and connects focused efforts at the Pennsylvania State University, the

University of Minnesota, Florida State University, the University of California, San Diego and the University of Maryland. The investigators involved in this project have an established history of a highly collaborative research style which will be efficiently brought to bear on the challenges posed in this award.

David Awschalom **06/01/01-02/28/06** **$252,448**
University of Pittsburgh, 400882-3

Quantum Information Processing with Ferroelectrically Coupled Si/Ge Quantum Dots

This award focuses primarily on probing the magnetooptical properties of Ge/Si quantum dots and semiconductor/ferroelectric heterostructures using time-resolved optical probes. This includes low temperature femtosecond-resolved spectroscopies such as Faraday rotation, spin-resolved absorption, and photoluminescence. In addition, we will conduct spatiotemporal studies of the energy-dependent spin landscape using our variable-temperature near-field optical microscopes to provide a high degree of spatial information.

Dirk Bouwmeester **07/01/03-06/30/04** **$100,000**
National Science Foundation, PHY-0334970

SGER: Exploratory Research into Producing Macroscopic Quantum Superpositions

We are conducting preliminary experiments to test the feasibility of a scheme for creating quantum superposition states involving of order 10^{14} atoms via the interaction of a single photon with a tiny mirror. Such quantum superpositions will be more massive than any quantum superposition observed to date by 10^{10} times and will therefore provide fundamental tests of quantum mechanics in an entirely new regime. The objectives of this Small Grant for Exploratory Research (SGER) is to give experimental evidence of the feasibility of integrating: 1. A high quality mirror on a cantilever. 2. A high quality stable optical cavity with one mirror as small as 10 microns. 3. Optical switching of a high quality mirror on picosecond timescales. 4. Stability isolation mechanisms with ultra-low cooling techniques in a vacuum.

Dirk Bouwmeester **08/15/03-07/31/07** **$1,560,000**
Lawrence Coldren
Pierre Petroff
National Science Foundation, PHY-0334970

NIRT: Quantum State Transfer Between Photons and Nanostructures

Photons have proven to be most useful for encoding special quantum states and for transmitting them through free space or optical fibers. For local quantum-state operations photons are less favorable and well-localized quantum systems are desirable. In this respect quantum dots, often referred to as artificial atoms, are particularly attractive. This research aims at combining the advantages of photons with those of artificial atoms. The main objective is to transfer the polarization quantum state of a single photon onto excitons in quantum dots and visa versa. The anticipated results are: a novel positioning technique for a quantum dot in the center of an optical waveguide, the demonstration of a single-photon absorption and reemission by a single quantum dot inside a micro-pillar with intrinsic lensing, the demonstration of the polarization quantum-state transfer between single photons and single quantum dots, and creating entanglement between a quantum dot and a photon and between two quantum dots. The first requirement to achieve the objectives is that the coupling between photons and quantum dots has to be resonant in order to preserve the quantum-phase coherences. For this optical-cavities resonant both with the incoming photon and the quantum dot inside the cavity will be used. Two novel ways of achieving a strong optical mode overlap with the quantum dots will be explored. The first is to use quantum dots inside micro pillars that containing optical lensing through the use of tapered oxidation layer. The second is to develop a technique to position a single quantum dot in the center of an optical micro cavity. The second requirement is that the quantum dots have to be effectively symmetric in order to obtain exciton spin degeneracy. For this magnetic fields and/or strain-induced effects on the micro-pillars will be explored. The third requirement is that the reemitted photon from the quantum dot should be distinguishable from photons reflected from the sample surface. For this a Michelson interferometer will be used where the two end mirrors are replaced by one micro-cavity containing a quantum dot on resonance and one micro-pillar containing no quantum dots on resonance. Reaching the objectives will be a major step forwards in quantum-state control and harnessing and understanding quantum decoherence in nano-structures. The research is based on a close collaboration between the Materials, Engineering and Physics Departments at the University of California Santa Barbara. This collaboration provides an excellent opportunity for young researchers to perform interdisciplinary research on important topics in quantum (and classical) communication and information processing and in nano-structure fabrication. Reaching the objectives will initiate future research in storage of quantum information and in implementing the quantum repeater scheme (enabling long-distance quantum cryptography), quantum error correction and quantum networks.

David Cannell **04/19/00-11/30/04** **$552,000**
National Aeronautics and Space Administration, NAG3-2439

Gradient Driven Fluctuations

We are doing the preliminary ground based work necessary to define a flight experiment for the International Space Station. The basic thing we will study is what effect gravity has on velocity fluctuations in a fluid or fluid mixture with either a concentration or temperature difference. It is already known that these fluctuations become very large, but are prevented from becoming huge by the effect of gravity. The fluctuations are predicted to become extremely large in the Space Station with no gravity. We are comparing two different techniques we could use to study the phenomenon of interest, and also trying different possible systems to find a few which are particularly well suited for the micro-gravity environment, i.e. non-toxic, very stable, and easily controlled.

David Cannell **12/04/03-11/30/07** **$479,000**
National Aeronautics and Space Administration, NNCO4GA45G

Gradient Driven Fluctuations

We will work with our collaborators at the University of Milan (Professor Marzio Giglio and his group-supported by ASI) to define the science required to measure gradient driven fluctuations in the microgravity environment. Such a study would provide an accurate test of the extent to which the theory of fluctuating hydrodynamics can be used to predict the properties of fluids maintained in a stressed, non-equilibrium state. As mentioned above, the results should also provide direct visual insight into the behavior of a variety of fluid systems containing gradients or interfaces, when placed in the microgravity environment.

Andrew Cleland **02/01/02-01/31/05** **$759,998**
Philip Lubin
Peter Meinhold
National Aeronautics and Space Administration, NAG5-11426

Nanobolometers and Single-Electron Readout Amplification

We are extending our efforts on nanoscale bolometers to explore four new main topics: Optical coupling of nanometer-scale integrated bolometric infrared detectors, developing integrated electronic refrigeration technology, developing single electron amplifiers for first-stage readout.

Andrew Cleland **12/31/98-12/30/03** **$32,592**
Research Corporation, UCSB 08981276

Nanostructured-Based Resonant Phonon Cavities: Can One Create a Coherent Phonon Source?

We are attempting to probe the potential of resonant phonon cavities, using coupled double quantum wells defined using electrostatic gates in a two-dimensional electron gas embedded in a suspended geometry to measure the phonon resonance spectrum of a double clamped flexural beam.

Steven DenBaars **11/26/03-11/25/04** **$65,000**
Shuji Nakamura
Hydro-Photon, Inc., SB040087

Compact Quantum Well AlGaN-Based UV Emitters for Water Purification

We will determine, confirm and compile the latest electrical, optical and mechanical specifications for the deep UV LED's. Radiometer work to quantify the UV output at <280 nanometers in terms of microwatts per square centimeter (u W/sq. cm.) at current inputs ranging from 20mA to >200 mA at 20mA increments will be performed. Minimum UV dose goal of >40 millijoules per square centimeter (40mJ/sq.cm.). UV emission data will help define approporaed dose period and water flow rate through the LED module. The project will include a reasonable efforts basis for fabrication and delivery to HPI of at least 10 UV LED's.

Elisabeth Gwinn **07/01/00-06/30/04** **$288,000**
National Science Foundation, DMR-0071956

Experimental Studies of the Edge-State Sheath on Quantum Hall Multilayers

This project investigates a new type of two-dimensional system, the surface-sheath of edge states that forms at the sidewalls of semiconductor multilayers in the quantum Hall regime. In conventional two-dimensional conductors, charge moves randomly in all directions. In contrast, on the edge-state sheath charge moves randomly perpendicular to the multilayer planes, but flows just one way around them. This chiral transport changes the interplay of disorder and interactions. We aim to use the edge-state sheath to advance understanding of the combined effects of disorder and interactions, an important problem in physics and materials science.

Elisabeth Gwinn **08/01/02-07/31/04** **$90,000**
National Science Foundation, ECS-0210281

Hybrid Organic-Inorganic Devices for Future Spintronic Applications

This project explores using the self-assemby of organic monolayers on inorganic substrates to control spin phenomena, namely magnetism. In these hybrid/inorganic devices, organic molecules with large electric dipole moments chemisorb onto an inorganic substrate, forming an organized, close-packed dipole sheet. The energetics of forming the adsorbate favors transfer of electrons between the organic molecules and the substrate, somewhat similar to the effects of gates in field-effect devices, but without the need for a gate or gate insulator. This chemically-induced charge tranfer modifies the electronic properties of both adsorbate abd substrate. Our purpose in this project is to carry out feasibilty experiments for spin-related phenomena in hybrid devices of organized organic adsorbates on inorganics.

Pierre Petroff **01/01/04-06/30/04** **$17,550**
Max Kade Foundation, SB030060

Optical Spectroscopy and Photon Statistics of Single Self Assembled Quantum Dots

Postdoctoral Research Exchange Grant

Mark Sherwin **02/01/01-01/31/04** **$646,307**
Arthur Gossard
Evelyn Hu
National Aeronautics and Space Administration, NAG5-10299

Quantum-Limited Terahertz Detection Without Liquid Cryogens

In this grant application, we propose to implement a novel semiconductor-based THz mixer, the Tunable Antenna-Coupled Intersubband Terahertz (TACIT) mixer. Modeling predicts that TACIT mixers are capable of nearly quantum-limited sensitivity for frequencies >1 THz at temperatures exceeding 20K, with intermediate frequency (IF) bandwidths exceeding 10 GHz and local oscillator power less than 100 nW. These specifications would enable missions with detectors cooled by relatively simple and compact mechanical coolers, and local oscillator power generated by solid state sources.

Mark Sherwin **08/15/00-07/31/03** **$308,486**
National Science Foundation, DMR-0070083

Terahertz Electro-Optics in Semiconductor Nanostructures

One of today's outstanding technological problems is the rapid communication of digital information. The threads of the internet are optical fibers, each of which has the potential to carry 40 trillion bits/s. Existing technology is capable of using only 1% of this bandwidth, by sending 10 gigabit/s on several dozen optical frequencies simultaneously. This research focuses on fabricating and testing a new class of nonlinear optical devices, which are capable of selectively shifting information carried on one optical frequency to another one several Terahertz away. The proposed devices are also expected to exhibit a variety of surprising phenomena which test our understanding of quantum-mechanical systems driven very far from equilibrium. For example, it is predicted that, for devices which are normally absorbing at NIR frequencies, strong THz irradiation can induce transparency. This research offers graduate students and undergraduates broad training in semiconductor physics, device fabrication, and optics which will prepare them for future careers in government, industry or academic science.

Mark Sherwin **06/01/03-05/31/06** **$397,000**
National Science Foundation, DMR-0244390

Terahertz Electro-Optics in Semiconductor Nanostructures

The research conducted under this grant explores the basic physics, fabrication, and materials science of semiconductor devices which can modulate light at THz frequencies. In addition to their desirability in the field of optical communications, semiconducting Thz electro-optic devices operate in a regime where the effects of quantum mechanics, strong driving, many-body physics, and dissipation are all important. This regime is one of the frontiers of condensed matter physics.

Mark Sherwin **08/15/03-07/31/06** **$425,000**
S. James Allen
Daniel Blumenthal
Pierre Petroff
Kevin Plaxco
National Science Foundation, DMR-0321365

Development of a Stable, User-Friendly, High-Power Terahertz Source: Enhancements to the UCSB Free-Electron Laser

The UCSB Free-Electron Lasers and newly-renovated User's Lab stand out as unique facilities which enable measurements that can be done nowhere else. The FELs work as follows. An electrostatic accelerator generates a beam of electrons with energies ranging from 2 to 6 MeV. The electrons are injected into one of two fully operational free-electron lasers before being recirculated. Narrow-band light emitted by the relativistic free-electron beam as it moves through the undulators in these lasers is amplified and trapped in a resonator. The small fraction which is coupled out is typically 1kW, tunable from 140 GHz to 5 THz, with pulse durations of a few s.

The three enhancements undertaken are: 1. Modernize control system 2. Stabilize frequency 3. Build a FEL spectrometer.

Mark Sherwin **10/02/02-** **$140,000**
Sun Microsystems, Gift

Research Support

This is an unrestricted gift in support of research in the "Center for Spintronics and Quantum Computation" project.

Vojislav Srdanov **07/01/02-08/31/04** **$80,000**
American Chemical Society, ACSPRF#38613-AC5

F-Center Spin Glasses

F-centers are point defects in an ionic lattice, consisting of an unpaired electron localized in the cavity of a missing anion. In certain types of sodalities, however, F-centers can be formed in every sodalite cage, thus giving rise to an ordered lattice of magnetically interacting F-centers known as electro-sodalite. We have found recently that alkali-electro-sodalites are Mott insulators with antiferromagnetic ground state, whose Neel temperature depends on the size of the alkali cation. We plan to introduce disorder in such a perfectly ordered bcc lattice of F-centers by filling sodalite cages with a desired percentage of randomly distributed, yet magnetically coupled, F-centers. The exchange interaction among such centers leads to spin frustration and thus offers studies of previously unknown F-venter spin glasses.

Vojislav Srdanov **07/01/01-06/30/05** **$248,275**
National Science Foundation, CHE-0098240

Photochemistry of Conjugated Polymer/Lanthanide Blends

The primary goal of this award is to understand charge transfer processes in the blends of lanthanide complexes in conjugated polymers (P/L blends) which will help application in emerging technologies. P/L blends profit from the good electrical conductivity of conjugated polymers which transfer the energy to luminescent rare earth ions. A rational design of these blends for use in either display or communication applications requires an improved understanding of the electronic coupling between organic semiconductors, the ligand on the complex, and the lanthanide metal center. To achieve these goals this award brings together an interdisciplinary research team with backgrounds in spectroscopy and organic synthesis.