ORAL PRESENTATIONS

All oral presentations take place in Dana I & II

Thurs. 10:00

PARCS Challenges

D.B. Sullivan
National Institute of Standards and Technology - U.S.A.

After presenting a very brief outline of this flight program, this paper will dwell in more detail on the key challenges that must be met for successful flight. These include the comparison of the frequency of the PARCS cesium clock with Earth-bound cesium clocks using the GPS carrier-phase method, the implementation of the phase modulation scheme needed to minimize the impact of space-station vibrations on the cesium clock, the evaluation of the cesium spin-exchange frequency shift, the design of shutters for the cesium beam, and the acquisition of tracking and acceleration data essential to measurement of the relativistic frequency shift and transfer of the realization of the second to Earth. Among advances to be reported in this paper are the development of the new concept of phase modulation and detailed analysis of the limitations of the carrier-phase frequency-comparison system. Preliminary designs for several key components of the flight package will be presented and discussed.

PARCS successfully completed its Science Concept Review in January 1999 and its Requirements Design Review in December 2000, and is now moving toward its Preliminary Design Review.

Thurs. 10:30

Electron Spin Resonance Investigations of Atoms Stabilized in Impurity-Helium Solids

David M. Lee
Laboratory of Atomic and Solid State Physics
Cornell University
Ithaca, NY 14853

The Electron Spin Resonance technique is employed to study atomic impurities (N, H, D) stabilized in Impurity-Helium (Im-He) Solids at 1.5-4.2 K. Samples are produced by sending a gaseous mixture of impurity particles (N_2, H_2 and/or D_2) and helium through a high power radiofrequency discharge onto the surface of superfluid ^4He. The rate of change of atomic populations in Im-He solids was measured for H, D, and N atoms. Low temperature tunneling exchange reactions ($D+H_2=H+HD$, $D+HD=H+D_2$) in samples containing simultaneously atoms and molecules of hydrogen and deuterium are observed. The kinetics of these reactions is investigated for samples with different contents of hydrogen and deuterium. Satellite lines associated with spin flips of protons on adjacent H_2 and HD molecules were observed around the hyperfine lines of both hydrogen and deuterium atoms. The (+-) to (-+) forbidden transition of hydrogen atoms was also observed.

Supported by NASA grant NAG 8-144

Thurs. 11:00

Dynamics near the critical point in heat flow

Akira Onuki
Kyoto University, Japan

First, we consider dynamics near the critical point in heat flow.

After a review of convection above T_c near the gas-liquid critical point, we discuss a new problem of two-phase convection, where bubble boiling and liquid condensation take place from the bottom and top boundaries. Here even for a very small temperature increase, a gas film appears at a heated surface due to enhanced thermal expansion near criticality. At larger heat input, the temperature gradient automatically assumes a unique small value (0.034 mK/cm for ^{3}He) in the interior of the cell, while it becomes mostly localized in the layers near the boundaries. Thus heat flow from below and phase separation are coupled to form unique self-organized convective states in the interior. Interestingly, this is analogous to formation of self-organized superfluid states in ^{4}He with high-density vortices under gravity and heat flow from above. These hydrodynamic effects are very sensitive to gravity.

Second, we show that the wetting properties are very sensitive to heat flow.

Thurs. 1:00

Oscillatory Transient Studies in the Convection of Supercritical ^{3}He

Horst Meyer and Andrei B. Kogan,
Department of Physics, Duke University

We analyze the observed transient pattern of the temperature difference $\Delta T(t)$ observed across a very compressible ^{3}He fluid layer in a Rayleigh-Bénard cell after starting the vertical heat flow q. The experiments are carried out along the critical isochore over the range $5x10^{-4} < \varepsilon < 0.2$ where $\varepsilon = (T-T_c)/T_c$ is the reduced temperature with $T_c = 3.318$K. The onset of the convection in the steady state, $\Delta T_{ons}(\varepsilon)$, is determined by the sum of the contributions from the Rayleigh and the Schwarzschild criteria. For $q > q_{ons}$, the transient $\Delta T(t)$ shows an overshoot, a truncated oscillation, before reaching the steady state value ΔT. With increasing q, this overshoot in $\Delta T(t)$ evolves into a damped full oscillation pattern with period t_{osc} (q,ε). The transient symptotically tends from below to the steady state ΔT in an exponential way with a relaxation time $\tau(q,\varepsilon)$. A scaled representation was obtained for both t_{osc}/t_D and for τ/t_D versus the Rayleigh number over 3.5 decades of Ra. Here $t_D(\varepsilon)$ is the characteristic diffusion time. The significance of these two scaled plots will be discussed.

The $\Delta T(t)$ patterns are compared with 2-D simulations that show these oscillations, which can be understood in terms of the "piston effect" in very compressible fluids kept at constant volume. There is good agreement in the oscillation rate over the range where damped oscillations are observed. A tentative “zone diagram” in the ΔT vs ε plane showing the various regimes of transient pattern will be presented.

Thurs. 1:30

RACE: Rubidium Atomic Clock Experiment

Kurt Gibble
Penn State University
University Park, PA 16802

We will present our progress towards RACE. Recently we have focused on juggling Rb atoms, high S/N detection, distributed cavity phase shifts, and the effect of microwave photon recoils.

Thurs. 2:00

Short-Range Inverse-Square Law Experiment in Space

Ho Jung Paik and M. Vol Moody
University of Maryland
College Park, MD 20742

Don Strayer
JPL, Caltech
Pasadena, CA 91109

Newton's inverse-square law is a cornerstone of General Relativity. Its validity has been demonstrated to better than one part in thousand in ranges greater than 1 cm. The range below 1 mm has been left largely unexplored, due to difficulties associated with designing sensitive short-range experiments. However, the theoretical rationale for testing Newton's law at ranges below 1 mm has become very strong recently.

The Standard Model of particle physics, although highly successful, has one serious blemish: the so-called "strong CP problem." Peccei and Quinn developed a very plausible explanation for this phenomenon over two decades ago, but experimentalists have so far failed to verify it. One ramification of the theory is the prediction of the existence of a new particle, called the "axion," which mediates a short-range mass-mass interaction, as well as a force between intrinsic spin and mass. The axion is also a strong candidate for cold dark matter.

Another impetus for testing the law at the shortest ranges possible comes from string theories. In these theories, the n extra spacetime dimensions are compactified, leaving the observed 3+1 spacetime dimensions. For n = 2, the law of gravity changes from 1/r2 to 1/r4, as r is reduced to below the radius of compactification, R. An intriguing possibility that R > 1 micrometer has been suggested recently, which would imply a violation of the inverse-square law at a level of 100 ppm at a 100-micrometer distance.

The objective of ISLES (Inverse-Square Law Experiment in Space) is to perform a null test of Newton's law on ISS with a resolution of 10 ppm at distances ranging from 100 micrometers to 1 mm.

This resolution presents an improvement by one million over the existing limits at 100 micrometers, and even greater improvement at shorter distances. ISLES will be sensitive enough to detect axions with the strongest allowed coupling and test the string-theory prediction with R greater than 300 nm. To reach this sensitivity, the existing superconducting accelerometer technology will be combined with advantages of the low-g environment of space.

The experiment will be cooled to below 2 K in LTMPF, which permits superconducting magnetic levitation in microgravity, allowing very soft, low-loss suspension of the test masses. The low magnetic damping, combined with a low-noise SQUID, leads to extremely low intrinsic noise in the detector. To minimize Newtonian errors, ISLES employs a near-null source, a circular disk of large diameter-to-thickness ratio. Two test masses, also disk-shaped, are suspended on the two sides of the source mass at a distance of 100 micrometers. The signal is detected by a superconducting differential accelerometer, which is a highly sensitive gravity sensor.

Direct vibration coupling between the source and the detector is reduced by over 300 dB by combining the differential measurement with second harmonic detection. Through careful matching and alignment, the device achieves a very high degree of decoupling from seismic acceleration in all degrees of freedom. The residual acceleration errors will be compensated by using acceleration signals from the auxiliary superconducting accelerometers. To reduce the errors due to the nonlinearities of the differential accelerometer, the actual displacements of the test masses will be reduced either by actively stiffening the resonant modes or by applying an active isolation to the LTMPF.

Thurs. 2:45

Splitting of vibrational modes of levitated drops

G.M. Seidel, C. Vincente, W. Yao and H.J. Maris
Brown University, Providence, RI

The surface energy of superfluid helium has been determined by measuring the vibrational frequencies of drops levitated in the Earth's gravity by a magnetic field. In the process of this investigation we have observed a splitting of the modes that depends on the applied field. The splitting of the l = 2 mode has been determined as a function a field. The lifting of the degeneracy of the oscillations of a free drop, the frequency for which is given by the Rayleigh expression, is due to the non-spherical potential at the position where the drop is levitated. The experimental results are found to be in good agreement with a calculation that takes into account both the deviation of the equilibrium shape of the drop from being spherical and the non-spherical restoring force introduced by the potential.

Thurs. 3:15

All-optical trapping and cooling of a two-component Fermi gas to degeneracy

John E. Thomas
Physics Department, Duke University
Durham, NC 27708-0305

We have achieved degeneracy in a mixture of the two lowest hyperfine states of ^{6}Li by direct evaporation in a CO_2 laser trap, yielding the first all-optically produced degenerate Fermi gas. More than 10^5 atoms are confined at temperatures below 4 K at full trap depth, where the Fermi temperature for each state is 8 _K. Trap lifetimes of 400 seconds are observed with residual heating rates less than 5 nK/s.

This degenerate two-component mixture is ideal for exploring mechanisms of superconductivity ranging from Cooper pairing to Bose condensation of strongly bound pairs. By preparing a single component degenerate Fermi gas for which s-wave scattering is suppressed, it will be possible to create noninteracting coherent superposition states with very long coherence lifetimes, potentially leading to improvements in precision measurements.

Thurs. 3:45

Predicting static and dynamic critical properties of confined helium

Efstratios Manousakis
Florida State University
Tallahassee, FL 32306

We have used state of the art simulation techniques to study confined helium and quantum films. First we will present our results on the finite-size scaling behavior of thermal resistivity near the lambda point of helium confined in pore-like geometry similar to the experiment BEST. Our calculated thermal resistivity obeys scaling using the same dynamical exponent found by Ahlers. In addition, our scaling curve is in reasonable agreement with the results of Kahn and Ahlers. Further investigation is required to study the role of boundary condition and geometry. At the present we are investigating the parallel-plate geometry. We will also present our results of a quantum simulation of sub-monolayer of molecular hydrogen deposited on a substrate consisting of ideal graphite substrate, using path-integral quantum Monte Carlo simulation. We find that the monolayer phase diagram is very similar to that of helium monolayer. Regardless of the complex nature of the monolayer phase diagram, we are able to reproduce its main features.

Fri. 8:30

Japanese research activities in fundamental physics discipline

Hiroto Kobayashi
National Space Development Agency of Japan
Space Utilization Research Center
Tsukuba, Ibaraki, JAPAN 305-8505

Japanese research activities in the fundamental physics discipline are reviewed, including 'Ground Research Announcement On Space Utilization.' Dynamical piston effect experiments using supercritical CO_2 are in progress in the Space Utilization Research Program of NASDA with the collaboration of National Aerospace Laboratory of Japan and Mitsubishi Research Institute, Inc. High-precision temperature control systems near room temperatures are established in this project. Six themes are selected in the fundamental physics discipline of the Ground Research Announcement and are yielding fruitful results. Future collaborations between space agencies will be discussed.

Fri. 9:00

Magnetism in a lattice of spinor Bose condensates

K. Gross, C. P. Search, H. Pu, W. Zhang, and P. Meystre
University of Arizona
Tucson, AZ 85721

Condensates of ^{87}Rb confined at each site of an optical lattice behave like mesoscopic spin magnets that can interact with each other through both magnetic and light-induced dipolar interactions. We show that for a blue-detuned lattice, such an array of spin magnets, can undergo a ferromagnetic or an antiferromagnetic phase transition, depending on the dimensionality of the confining lattice. We discuss the ground state spin configuration and related magnetic properties of these systems.

Fri. 9:30

MISTE Flight Experiment Status

M. Barmatz, Fang Zhong, Inseob Hahn and M. Weilert
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA 91109

The MISTE flight experiment has made significant scientific and technical progress in preparing for a future microgravity flight. We are collaborating with several theoretical modeling groups that have developed crossover (equation-of-state) models for predicting thermodynamic behavior near the liquid-gas critical point. Computer codes for these models are being prepared in preparation for analyzing future MISTE flight data. Several of these models have already been used to test experimental measurements of the heat capacity at constant volume, isothermal susceptibility, and coexistence curve in the crossover region near the 3He liquid-gas critical point. A brief description of these models and a comparison of their fit to experimental data will be presented. An important technical advancement required for the successful completion of the MISTE flight experiment is the development of a low temperature valve that can be actuated multiple times. In collaboration with Mission Research Corporation, MISTE has been testing a new small pneumatic valve for use at low temperatures. The results of recent successful low temperature actuation tests will also be discussed.

Fri. 10:15 **Discussion Session on “Opportunities for guest investigators on flight experiments”**

Led by: Ulf Israelsson
Feng-chuan Liu
Lute Maleki

Fri. 1:00

Towards Testing Fundamental Physics with Ultracold Bose and Fermi Gases

Kai Dieckmann
MIT
Cambridge, MA 02139

Recent results of the MIT group cover several directions. We are studying phenomena in ultracold gases with astrophysical implications. Our studies of vortices in superfluid gases are related to the physics in the interior of neutron stars. We have extended our research to ultracold fermions, by cooling fermionic lithium-6 sympathetically with a sodium Bose-Einstein condensate. Quantum-degeneracy in fermions is key to the properties of neutron stars and white dwarfs. Currently, we are studying the possibility of tuning the interactions between the fermions in the vicinity of a Feshbach resonance.

We have also done steps towards precision interferometry with Bose-Einstein condensates. A novel scheme employing contrast interferometry was realized and several advantageous properties of this method have been demonstrated. The method can be scaled to perform a high precision measurement of the recoil frequency and therefore contribute to the determination of the fine structure constant. This experiment was done with free-falling condensates and will ultimately be limited by the finite observation time due to gravity.

Furthermore, we have merged ultracold atoms with microchip technology. A large condensate was loaded into an atom chip consisting of microfabricated wire arrays deposited on a substrate. A single-mode waveguide for matter waves was demonstrated. The miniaturized, light technology greatly enhances the control over the atoms for atom interferometry and the study of quantum liquids.

Fri. 1:30

The Fluctuations of the Phase Difference Across An Array of Josephson Junctions

Talso Chui and Warren Holmes
Jet Propulsion Laboratory
Pasadena, CA 91109

We present calculations of the thermodynamic fluctuations of the phase difference Δ across an array of Josephson junctions in superfluid ^{4}He. We use a model of the Josephson effect, analogous to a rigid pendulum, to understand the dynamics of Δ_in the limit of large fluctuations. In this model, the angle sustained by the pendulum is analogous t__Δ. We show that the rms fluctuations of Δ_increase as the lambda transition is approached. At a critical value ofΔ, the fluctuations of Δ_can excee__2π causing a continuous phase slip. The probability of a phase slip increases closer to the lambda point until Δ (t) becomes chaotic and the Josephson effect disappears. We show that the mean square fluctuations of Δ_decrease ~ 1/N, where N is the number of orifices in the array. We show that for a single junction of dimension LxLxL, near the lambda transition where the correlation length is ~L, there is already a significant probability of phase slip. This means that the Josephson effect does not occur in a single junction but does occur in an array of such junctions.

Fri. 2:00

Progress on two superfluid gyroscopes

Richard Packard
University of California
Berkeley, CA 94720

We are developing two types of sensitive superfluid rotation sensors, i.e gyroscopes. One type is based on phase slippage in He-4. This device has advanced to a 13-turn pickup loop with 100 cm^2 enclosed area. We find that there is no long-term drift and that there are no detectable unknown noise sources. Our present device displays the intrinsic noise floor of about $5x10^{-3}$ of the Earth's rotation rate. Our second device is a proof-of-principle prototype based on the DC Josephson effect in He-3. We have made the analog of a DC-SQUID and modulated the current by reorienting the pickup loop with respect to the Earth's rotation axis. Our first instrument includes a pickup area of 6 cm^2 and the noise is due to ambient building vibrations, not intrinsic processes.

Fri. 2:30

Quantum Phase separation dynamics of BEC mixtures

S. T. Chui
Bartol Research Institute, University of Delaware
Newark. DE 19716

We discuss our recent work on phase separation dynamics in mixtures of Bose-Einstein condensates. We show that the coupled two component one-dimensional Gross-Pitaevskii equations can be solved by the inverse scattering method. This opens the door for the investigation of different excitations for the two by constructing exact extended periodic solutions of this equation. We call these type solutions ``striatons", in analogy to solitons that are localized solutions. Our solution suggests that the experimentally observed long-lived metastable intrinsic straition structure is a new kind of excitation of the two component Bose-Einstein condensates. We can find these solutions only in some region of parameter space. We numerically solved the coupled GP equations for different system parameters and found fascinating scenarios of the space time development of the density distributions. Only in some parameter regimes is the periodic fluctuation stable.

Fri. 3:15

The Capabilities of the Low Temperature Microgravity Physics Facility for Performing Science

Melora Larson, Arvid Croonquist, G. John Dick, and Yuanming Liu
Jet Propulsion Laboratory,
California Institute of Technology,
Pasadena, California 91109

The Jet Propulsion Laboratory (JPL) is developing the Low Temperature Microgravity Physics Facility (LTMPF). The LTMPF is a multiple-user and multiple-flight facility that will provide a long-duration low temperature environment for performing state-of-the-art experiments at the International Space Station (ISS). The LTMPF will fly attached to the Japanese Experiment Module (KIBO) Exposed Facility of the ISS, and the LTMPF will be ready for an initial flight in late 2005. The LTMPF is a self-contained, reusable, cryogenic facility containing a 180-liter superfluid helium tank, two experiment packages, and electronics to provide both control and telemetry. During each mission, two distinct primary experiments will be accommodated. Secondary experiments utilizing the hardware built for the primary experiments will also be accommodated during each mission. The detailed technical capabilities related to the science enabled by the Facility will be presented to illustrate how the LTMPF will provide a platform for breakthrough scientific investigations requiring both low temperatures and microgravity conditions.

Fri. 3:45

Formation and Propagation of Matter Wave Solitons

Randall Hulet
Rice University
Houston, TX 77005

Solitons arise in wave phenomena when a nonlinearity exactly compensates for wavepacket dispersion. This compensation enables a soliton to propagate without the usual spreading associated with wavepackets. Solitons are observed in a variety of wave phenomena, including water waves, plasma waves, and optical pulses, to name but a few. We have exploited the nonlinear interactions between atoms in a Bose-Einstein condensate of ^{7}Li to form matter wave solitons in a one-dimensional (1-D) optical trap. By changing the interactions from repulsive to attractive, the condensate is observed to form a remarkable multi-soliton "train" of up to 15 individual solitons, each of which is a Bose-Einstein condensate. We set the soliton train in motion by displacing it from the center of the harmonic trapping potential and releasing it. The solitons are observed to maintain their size and shape for a propagation time of up to 3 s. The train forms with alternating phase between nearest neighbors. This phase structure gives rise to a repulsive interaction between neighboring solitons, whose effect can be seen in their relative motion. The number of solitons produced is observed to increase linearly with the initial velocity of the condensate, which we ascribe to the phase-gradient imposed upon the condensate by its motion. The dynamical process of soliton formation is fascinating and much remains to be learned.

We are pursuing the possibility of creating Cooper pairs of fermionic ^{6}Li atoms, the atom analog of superconductivity. Our scheme for doing this involves many of the experimental ingredients of the soliton demonstration. Specifically, the formation of Cooper pairs relies on tuning the interactions between ^{6}Li atoms to strongly attractive using a magnetically tuned "Feshbach resonance".

Fri. 4:15

Space-Based Searches for Lorentz and CPT Violation

Alan Kostelecky
Physics Department, Indiana University
Bloomington, IN 47405

Nature appears invariant under Lorentz and CPT transformations. However, small violations of these symmetries might arise from Planck-scale effects. A variety of experiments can test this possibility, including ones based on the International Space Station and other spacecraft.

Fri. 4:45

Atom-atom collisions in a very dense Bose-Einstein condensate

Juha Javanainen
University of Connecticut
Storrs, CT 06269-3046

In a dense enough Bose-Einstein condensate, the binary collision approximation underlying the usual description of atom-atom interactions must break down. We propose a new paradigm for the theory of atom-atom interactions in a very dense, quantum degenerate gas: resonance between atomic and molecular condensates. We demonstrate how this way of thinking reproduces the usual collision theory in the limit of a dilute condensate, and report on progress toward finding experiments in which the new approach differs from the standard picture.

Sat. 8:30

Measurement of G with an atom interferometer based gravity gradiometer

Greg Foster
Yale University
New Haven, CT 06511-8120

We report the progress of measurements to determine the Newtonian gravitational constant G with an atom interferometer-based gravity gradiometer. We detect the gravity gradient from a 500 kg lead source mass. Knowledge of the source mass density and geometry coupled with the trajectory of the atoms allows us to calculate the expected gradient. The comparison of the theory and measurement determines a value for G. The measurements probe the accuracy of the gradiometer and atom interferometry theory. We are presently studying the instrument response to a variety of systematic effects.

Sat. 9:00

Experimental observation of critical Casimir forces

Rafael Garcia
Penn State University
University Park, PA 16802

The critical Casimir force is a direct analog of the Casimir force in electromagnetism, a force between two metal plates that is mediated by the confined zero point electromagnetic fluctuations. Instead of being mediated by zero point electromagnetic fluctuations, however, the critical Casimir force is predicted to be mediated by thermal fluctuations of a fluid's order parameter near its critical point[1]. I will present recent dielectric constant measurements of the thickness of helium films adsorbed on Cu which provide evidence for the existence of the critical Casimir force near the superfluid transition in He-4 and near the tricritical point in He-3-He-4 mixtures[2]. In pure He-4, we find the force is attractive but near the tricritical point the force appears to be repulsive(!). This change in the sign of the force is explained by a change in the boundary conditions that the order parameter[3]. Preliminary efforts are also underway to measure this force near the liquid-vapor critical point. This work was done in collaboration with Moses Chan and funded by NASA's Office of Biological and Physical Research under NAG8-1761.

[1] M. E. Fisher and P.-G. de Gennes, C. R. Acad. Sci. Paris Ser B 287, 209 (1978); M. P. Nightingale and J. O. Indekeu, Phys. Rev. Lett. 54, 1824 (1985); M. Krech and S. Dietrich, Phys. Rev. Lett. 66, 345 (1991).
[2] R. Garcia and M. H. W. Chan, Phys. Rev. Lett, 83, 1187 (1999); Phys. Rev. Lett. 88, 086101 (2002).
[3] J. O. Indekeu, J. Chem. Soc. Faraday Trans. II 822, 1835 (1986); M. Krech, J. Phys.: Condens. Matter 11, R391 (1999).

Sat. 9:30

Finite-size effects on the conductivity of He-4 near the superfluid transition

Guenter Ahlers
University of California
Santa Barbara, CA 93106

We will present experimental data for the thermal conductivity of He-4 near the superfluid transition in finite cylindrical and rectangular geometries and discuss the corresponding finite-size scaling functions.

This work was done by Edgar Genio, Daniel Murphy, Yuanming Liu, Fengchuan Liu, and Guenter Ahlers. The work was supported by NASA Grant NAG8-1429 and is part of the Flight Definition Project Boundary Effects on the Superfluid Transition (BEST).

Sat. 10:15

Experiment to Measure the Electric Dipole Moment of the Electron

Daniel Heinzen
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Austin, TX 78712

The electric dipole moment (edm) of the electron d_e is known from previous measurements to be smaller in magnitude than 1.6 10^{-27} e cm [1]. This result follows from a measurement of the electric dipole moment of paramagnetic Tl atoms using conventional atomic beam techniques. A nonzero value of de can exist only if time reversal symmetry (T) is violated. T-violation within the standard model is far too small to allow for a measurable value of d_e, but extensions of the standard model, such as low-energy supersymmetry, do allow for a value of d_e that could be as large as about ten times the current experimental bound. More sensitive experiments might therefore detect a nonzero value of the electron edm, and provide unambiguous evidence for new physics beyond the standard model. Alternatively, a more sensitive null result would provide further significant constraints on new models of physics. In this talk, we will describe the design of our new experiment to measure the electric dipole moment of the electron using laser cooled Cs atoms. The atoms will be trapped in a far-off resonance optical dipole force trap between electric field plates, and placed within magnetic shields. This experiment has the advantages of long coherent interaction times, resulting in very narrow transition line-widths, and of suppression of velocity dependent errors. Crucial issues include AC Stark shifts induced by the trapping laser fields, and the high degree of magnetic shielding required. This experiment has the potential to yield a sensitivity to a nonzero d_e of the order of 1.0 10^{-29} e cm, which would represent an advance in sensitivity of about two orders of magnitude.

[1] B. C. Regan et al, Phys. Rev. Lett. 88, 071805 (2002).

Sat. 10:45

Experiments Along Coexistence near Tricriticality in ^{3}He-^{4}He Mixtures

Melora Larson(a), Vladimir Dotsenko(b), Ashutosh Tiwari(b), Masoud Mohazzab(b),
Norbert Mulders(b), Alfred Nash(a), John Panek(c), and Ben Vollmayr-Lee(d)

(a) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109
(b) Department of Physics and Astronomy, University of Delaware, Newark, DE 19716
(c) Goddard Space Flight Center, Greenbelt, MD 20771
(d) Department of Physics, Bucknell University, Lewisburg, PA 17837

The tricritical point in the phase diagram of 3He-4He mixtures offers unique opportunities to test our understanding of critical phenomena. Because D = 3 is the marginal spatial dimension for tricriticality, the associated critical exponents are exact integer fractions. In addition, one expects to find logarithmic corrections. We present our results for the superfluid density, obtained from time-of-flight non-linear second sound measurements near the tricritical point and along the phase separation curve. We also report on our measurements of the phase separation curve near the tricritical point performed using inter-digital capacitor sensors on the top and bottom of our cell.

Sat. 11:15

New Measurement of Cesium Polarizability Using Laser-Cooled Atoms

Harvey Gould and Jason Amini*,
Lawrence Berkeley National Laboratory

Berkeley, CA 94720

We report the first improvement in the determination of α_{Cs}, the cesium dipole polarizability, in over 25 years, reducing the uncertainty from 2% to about 0.4%. This makes α_{Cs} the most precisely measured polarizability in any element except the noble gases.

The polarizability of an atom α is its response to an external electric field and is defined by W = -1/2 α E*E where E is the electric field and W is the potential energy. Atomic polarizability enters into the dielectric constant, index of refraction, van der Waals constant, and the black-body radiation shift in atomic clocks.

For an atom passing through an electric field gradient, such as the entrance of a set of parallel plate electrodes, the change in kinetic energy is equal to the change in potential energy. α_{Cs} can be determined from the increase in velocity of the atom from v outside the field to v' inside the field: v' = sqrt(v*v - W/2m), where m is the mass of the atom.

Using a beam of laser-cooled atoms makes it possible to use small v and hence to measure the small change in velocity due to α_{Cs}. Results and details of the technique will be presented.

In future work, the apparatus may be used to assess the feasibility of a microgravity electron electric dipole moment experiment.

Work supported by NASA and the U.S. DOE under contract DE-AC 76SF00098.
Also Dept. Of Physics U.C. Berkeley

Sat. 1:00

New measurement technology for thermometry and heat flux control

Robert Duncan
University of New Mexico
Albuquerque, NM 87131-1156

New measurement technologies have been developed to advance thermometry and heat flux control for low-temperature, fundamental physics experiments. The DYNAMX and CQ experiments plan to use a new layered aluminum cell endcap design that will spread heat from a small surface-mount resistor uniformly across a 2.5 cm cell diameter using only a 0.5 cm thick endcap. The bubble chamber mounted on the top endcap is thermally isolated so that the surface area within the bubble chamber does not contribute to the heat flow out of the He-II, assuring uniform heat flux through the cross section of this endcap.

Thin films and microstructures of dilute Mn magnetic ions in Pd have been prepared by sputtering bulk PdMn material on machined glass and sapphire substrates for use in spatially resolved thermometry and bolometry. The thermal sensitivity of these thin film devices have been measured as a function of magnetic field and temperature, showing complex thermomagnetic behavior that varies with the film thickness. The thermomagnetic performance of these films is easily controlled and non-hysteretic, so

that these devices may facilitate many new experiments in the study of the quantum fluids.

This work has been performed in collaboration with D.A. Sergatskov, R.C. Nelson, A.V. Babkin, S.T.P. Boyd, T.D. McCarson, A.M. Churilov, R.A.M. Lee, D.L. Goodstein, and A. Chatto, and is supported by the Fundamental Physics Discipline within the Microgravity Science Office of NASA.

Sat. 1:30

High Density Trapped Atoms in a Holographic Atom Trap

Thad Walker
University of Wisconsin-Madison
Madison, WI 53706

We will present our technique for loading high densities of laser cooled 87Rb atoms into a Holographic Atom Trap (HAT). The HAT is formed by the interference of five YAG beams produced by a holographic phase plate, of typically 12 W total power. The interference pattern creates clusters of 10 micron x 10 micron x 100 micron microtraps. The microtrap oscillation frequencies of 18 kHz, 18 kHz, and 700 Hz permit high densities and phase space densities with modest temperatures and numbers of atoms. We have routinely been able to achieve peak densities of 2e14 atoms/cc in the HAT. Such small volume, high density sources of atoms are of considerable interest for mesoscopic quantum manipulation and entanglement. In particular, single-atom and single-photon sources should be possible using the Rydberg dipole-blockade concept with the HAT microtraps.

This work was done in collaboration with R. Newell, J. Sebby, and M. Saffman, and supported by NASA and the NSF.

Sat. 2:00

High-order inertial force phase shifts for microgravity optical clocks and inertial sensors

Kai Bongs
Yale University
New Haven, CT 06511-8120

High-order inertial phase shifts are calculated for time-domain atom interferometers. We obtain closed-form analytic expressions for these shifts in accelerometer, gyroscope, optical clock and photon recoil measurement configurations. Our analysis includes Coriolis, centrifugal, gravitational, and gravity gradient-induced forces. We identify new shifts which arise at levels relevant to planned microgravity experiments.

POSTER PRESENTATIONS

Thursday 4:30-6:30 in the Catalina Room

Measurement Techniques For The Study Of Dynamic Effects In Phospholipid Surfactants

Neha M. Patel, M. Reza Dodge, Charles Rosenblatt* and Philip L. Taylor
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The effective functioning of the human lung is dependent on the modification of surface tension by lipids at the air-water interface. Our understanding of this problem is limited by the difficulty presented by physical measurements of this interface, which generally contains a complex mixture of lipid surfactants and proteins that act in concert to modify the behavior of the surface as it undergoes changes in area, temperature, and gas composition. The goal of this research is to develop techniques for the measurement of the dynamic surface tension of lung surfactants using methods requiring only small amounts of material, as existing techniques usually require a large amount of fluid in which a captive bubble of air can be subjected to a time-varying pressure. One promising approach is to study the response of miniature liquid bridges to time-varying forces.

We have conducted experiments designed to provide rapid and reliable measurements of the dynamic properties of biologically important surfactants under a wide variety of conditions. The essence of our technique rests on our ability to simulate a microgravity environment, as well as to vary the total body force with time. We achieve this by use of a strong magnetic field gradient, which can counteract gravity. In one embodiment of this technique we perform resonance measurements on surfactant-coated liquid bridges without the perturbing effects of the sagging of a bridge normally encountered in an Earth-based experiment. The resonance behavior is observed by remote imaging. In a second embodiment we make a sudden change in bridge length by mechanical means, and measure the electrical conductance of the bridge as a function of time.

Precision Studies of Relativity in Electrodynamics

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Violations of Lorentz symmetry form a sensitive candidate signal for new physics at the Planck scale. Effects in electrodynamics can be studied within a general framework extracted from a theory incorporating the standard model of particle physics and allowing small corrections to relativity and CPT symmetry. Recent infrared, optical, and ultraviolet polarimetry of distant cosmological sources is used to constrain possible effects. The Lorentz reach of some future ground- and space-based experiments is studied.

Spin-Mass Interaction Low-temperature Experiment on ISS

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The Standard Model of particle physics has had spectacular success in explaining all available data on the fundamental constituents of matter. However, one of the most important unresolved issues is the "strong CP problem," which leads to an electric dipole moment of the neutron one billion times larger than the present upper limit. Peccei and Quinn developed a very plausible explanation for this phenomenon over two decades ago, but experimentalists have so far failed to verify it. One ramification of the theory is the prediction of the existence of a new particle, called the "axion," which mediates a force between intrinsic spin and mass. The axion is also a strong candidate for dark matter, which represents the majority of mass in the universe. Confirmation (or rejection) of this prediction would therefore have a major impact on our understanding of the universe, from its most microscopic constituents to its grand structure.

SMILE (Spin-Mass Interaction Low-temperature Experiment) is an ISS experiment capable of approaching, to within a factor of 100, the spin-mass interaction allowed for the axion. This improves over previous experiments by nine orders of magnitude. To reach this sensitivity, the existing superconducting accelerometer technology will be combined with advantages of low-g environment of space. With support from Code U of NASA, we have already designed and constructed an apparatus for ground test. A slightly modified instrument, flown in LTMPF on ISS, will improve the limit of spin-mass interaction by over eight orders of magnitude from the existing limit. Although the possible detection of the axion at the level allowed may take an experiment on a quieter free-flyer, SMILE will search for a generic spin-coupling force in the large parameter space that has been never been explored and constitutes an important new test of General Relativity.

To achieve the required sensitivity, the intrinsic noise of the instrument, as well as its isolation from seismic, gravitational, and electromagnetic disturbances, must all be greatly enhanced. The Brownian motion provides the ultimate limit of sensitivity for a gravity experiment. To reduce this noise, the damping coefficient of the test mass, as well as its temperature, must be minimized. The low-g environment of space permits nearly free suspension of the test mass, under which the highest resonance quality factor can be attained, limited only by interaction with residual gas molecules.

SMILE employs a superconducting differential angular accelerator, a very sensitive force sensor. However, to reach the gas-damping limit of sensitivity, the amplifier noise must be suppressed. We achieve this by driving the source at the resonance frequency of the detector. The resonant gain of the signal then makes the amplifier noise relatively insignificant. The differential accelerometer is also capable of rejecting the linear and angular accelerations of the platform to extremely high precision. This permits the required high sensitivity to be achieved on ISS without vibration isolation.

The spin source is an elongated toroid with alternating sections formed from two high-permeability materials with different saturation spin densities. The detector consists of two identical angular accelerometers. The accelerometer test masses are magnetically levitated and have cylindrical symmetry to high order. A superconducting shield isolates the test masses from the magnetic field of the source. The spins in the source materials are modulated by an ac current through the coil wound on the source. The cylindrical symmetry and angular sensing makes the instrument insensitive to gravitational disturbances and forces from electric charge and temperature gradients.

Interdigital Capacitor as Solid He-4 Height Detector

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A compact interdigital capacitor is being developed as a level detector of solid He-4. The capacitor consists of 38 interlaced 50 mm wide and 3.8 mm long gold films separated by 50 μ and deposited onto a 5 X 5 mm^2 sapphire substrate. The background capacitance is 6.5 pF. The capacitance change is $1.3x10^{-3}$ pF/mm of solid He-4 height change. A height change of 20 _m is detectable at present. Preliminary observations of hcp solid He-4 growth have been made at 1.2 K in a 6.7mm x 8.7mm x 9.1 mm cell made of copper. The solid is made to grow or melt slowly by applying heat to an external pressure bomb cooled to 77 K. Observations show overpressures (measured with a low temperature strain gauge) up to 25 mbar prior to nucleation of solid. The overpressure is highly dependent on each cool down from 300 K. The rate of growth may be controlled by varying heat to the pressure bomb.

Innovative Quantum Technologies For Microgravity Fundamental Physics And Biological Research

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The many advanced technology requirements dictated by the demanding low-Earth orbit research environment can only be satisfied through the adaptation of innovative methods and technologies. The fundamental physics research program in microgravity sponsors research that explores the physics governing matter, space, and time and that seeks to discover and understand the organizing principles of nature, including the emergence of complex structures. The fundamental physics research program currently supports research in four areas: gravitational and relativistic physics, laser cooling and atomic physics, low temperature and condensed matter physics, and biological physics. The microgravity fundamental physics is one of the science disciplines within the new NASA Office of Biological and Physical Sciences Research, where quantum technology plays a major role. Quantum technology, based on controlled manipulation of fundamentally quantum processes of atoms, molecules, or soft matter, enables novel and significantly extended capabilities. This poster presents a new technology program, within the fundamental physics research program, focusing on four quantum technology areas: quantum atomics, quantum optics, space superconductivity and quantum sensor technology, and quantum fluid based sensor and modeling technology.

Improved flow cells for rapid mixing experiments using x-rays and fluorescence

microscopy

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We have redesigned a previous version of a microfabricated flow cell to achieve two specific goals. The first is the optimization of signal to background for x-ray scattering experiments on both protein and RNA folding. To achieve this goal, we have nanofabricated ultra-thin silicon nitride windows for the sample cell. The second improvement allows sharper time resolution by creating a more homogeneous flow profile inside the mixing cell. Preliminary results of an RNA folding experiment, recently performed at the Cornell High Energy Synchrotron Source (CHESS) will be presented, showing that the new design significantly reduces the background signal.

The mixing cells have also recently been used to monitor rapid (microsecond scale) conformational changes in proteins using multi-photon and confocal microscopy. Preliminary results from experiments on fluorescently-labeled calmodulin will \also be presented.

Tests of CPT and Lorentz symmetry using atomic masers

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We are developing improved $^{21}Ne/^{3}He$ and hydrogen masers for high precision tests of CPT and Lorentz symmetry of the neutron and the proton, respectively. Current results will be presented.

Turbidity in a density-matched system

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The turbidity of a density-matched, liquid-liquid mixture has been measured very near its critical point. Understanding critical phenomena in simple systems, as in the liquid-liquid system studied here, is essential both to test theory and to serve as a model system for more complex behavior near a critical point. We are conducting a ground based (1-g) experiment that measures the turbidity of methanol-cyclohexane extremely close to its critical consolute point. By covering the range of reduced temperatures $t=(T-T_c) / T_c$ from 10^{-8} to 10^{-2}, the turbidity measurements allow the Green-Fisher critical exponent ψ to be determined. The turbidity data can also be compared to the theoretical approximation developed by Ferrell and to a recent Monte Carlo simulation. These two results predict very different behavior for the turbidity when very close to the critical point and our experiment can help address the differences.

Correlation length of perfluoroheptane and 2,2,4-trimethylpentane

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The turbidity of the liquid-liquid mixture perfluoroheptane and 2,2,4-trimethylpentane (also known as iso-octane) has been measured and used to determine the correlation length amplitude. By measuring the ratio of the transmitted to incident light intensities over three decades in reduced temperature, we are able to determine that that amplitude to be 0.242 ± 0.009 nm. This value differs significantly from that reported in the literature. When we combine this value with the amplitude A+ determined in a recent heat capacity measurement on this system, the two-scale-factor universality constant X is 0.0177 ± 0.0018, which is quite consistent with other determinations between 0.018 and 0.020.

Compressibility measurements near the critical point of oxygen

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We describe preliminary results for the behavior of the compressibility of oxygen near its critical point obtained with an apparatus that reduces gravitational compression effects on the fluid. The results extend deeper into the asymptotic region near the critical point than was achieved in earlier experiments. The system uses magnetic levitation to reduce the hydrostatic compression of every element within a fluid and is capable of applying forces of ± 3 g to a sample of oxygen. By performing critical point experiments with gravity cancelled on earth, the need for scarce flight resources to study this field of physics can be reduced, leading to substantial savings for the taxpayer. Also, the time available for experiments can be much longer than anticipated in upcoming flight missions, especially those using low temperatures. The apparatus can be used for high resolution measurements of the equation of state, the coexistence curve, the specific heat, and transport phenomena.

Electrostatic Focusing of Laser-Cooled Atoms

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Neutral atoms can be transported and focused by a sequence of electric fields having gradients that alternately focus in one transverse direction while defocusing in the other. Efficient electrostatic transport and focusing of atoms has been difficult to realize in practice because commonly used cylindrical lenses contain strong electric multipoles of all odd orders. This limits the linear region of the lens to a small fraction of the available area. Nonlinearities result in loss of beam, generation of beam halo, and growth in the transverse emittance producing larger beam sizes.

We show how to design electrostatic lenses containing only dipole and sextupole components (and a small decapole contribution) resulting in lenses that have a large linear region [1]. These lenses can be combined to transport laser-cooled atoms over nearly unlimited distances and to focus them.

The applications are in atomic clocks in space, manipulating Bose Einstein condensates, and electron electric dipole moment experiments.

Work supported by the U.S. DOE under contract DE-AC-76SF00098.

[1] J.G. Kalnins, G. Lambertson, and H. Gould, "Improved alternating gradient transport and focusing of neutral molecules," accepted for publication in Rev. Sci. Instr. (http://arXiv.org/abs/physics/0112073.).

Single Laser-Cooled Ion Trapping at the University of Washington

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It is generally accepted that single, laser-cooled ions have some very favorable qualities which greatly aid in ultra-high resolution spectroscopy: They are free from transit-time shifts, Doppler shifts (to all orders), collision shifts and (with appropriate choice of species) are free from magnetic and electric field shifts. As a result, they are excellent candidates for an optical frequency/time standard, where the very high clock frequency together with this freedom from shifts makes an optical standard with an inaccuracy of one part in 10^{18} a reasonable near-term goal. These experiments are facilitated by the use of the "shelving" technique to extract the maximum amount of information from this very small sample of one ion. It is also possible to use "shelving" with single laser-cooled ions to perform extraordinarily precise radio-frequency spectroscopic measurements. This presentation will describe experiments of both types. In particular, optical spectroscopy using single indium ions will be discussed with data presented on moderate-resolution "clock" transition resonances, which should very soon be narrowed by at least a factor of 1000. In addition, the technique of "spin-sensitive-shelving" will be described and recent 15-Hz wide radio-frequency transitions in single barium ions using this method will be presented. Finally, future light-shift and electric-quadrapole-shift measurements in single barium ions will be discussed.

Test of the Equivalence Principle in an Einstein Elevator: a first-year progress report

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Our poster reports the progress on the flight definition of an experiment to test the Equivalence Principle in free-fall inside a co-moving vacuum chamber/cryostat. This chamber is part of the falling capsule that is released from a balloon at stratospheric altitude. The analysis has concentrated on the study of key noise sources such as gravity gradients generated by distributed (capsule) and concentrated (equipment) masses near the detector. The result has led to the choice of mass distribution and to the determination of the relative motion requirements. Data on the sensitivity of similar detectors to temperature has enabled the computation of limits on the tolerable temperature drift rates for the accelerometer and its preamplifier during the fall. We were thus able to sketch out a preliminary thermal design of the free falling package. Results of capsule dynamics analysis and gravity gradient effects have been utilized in a design optimization process aimed at selecting suitable masses and sizes for the drop capsule. Finally, we estimated the contribution of the parity violating weak interactions to the mass-energy of various materials to determine whether the experiment might have sufficient sensitivity to probe this mass-energy contribution.

Progress in Developing a Superconducting Microwave Oscillator for Precision Measurements on Orbit

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We describe the development of a superconducting microwave oscillator with high frequency stability for use aboard the International Space Station. The project has four main goals; an improved test of Local
Position Invariance, improved Kennedy Thorndyke and Michelson-Morley special relativity tests, and an enhancement of the performance of atomic clocks being developed elsewhere for use in space. In addition precision clocks play an important role in experimental tests of Lorentz and CPT violation. Aboard the International Space Station, unwanted resonant-frequency variations are expected to be caused mainly by acceleration effects due to residual drag and vibration, temperature variations, and fluctuations in the energy stored in the cavity. In the past, acceleration effects appeared to be the predominant limit. A new cavity support system has been designed to reduce the acceleration effects and a fractional frequency stability of 1 part in 10^{17} per μg has been demonstrated.