Oral Presentations
(listed alphabetically by author's last name)

Guenter Ahlers, Department of Physics, University of California, Santa Barbara CA 93106, *Mon., 11:20-12:05,* Some Provocative Unresolved Problems in Rayleigh-Benard Convection: This talk will address a number of experimental observations or measurements pertaining to pattern formation in Rayleigh-Benard convection (RBC) which fall into one or both of the following categories: 1.) They seem interesting but have never been addressed theoretically, 2.) They disagree with theoretical predictions. Included are: a.) the re-emergence of relatively simple patterns in cylindrical samples at large Rayleigh numbers; b.) Unorthodox correlation-length scaling and defect formation in domain chaos, i.e. in RBC with rotation; c.) Formation of "squares" where Kuppers-Lortz-unstable rolls are predicted in RBC with rotation; d.) A subcritical bifurcation without hysteresis in RBC with rotation; e.) Absence of convection above a predicted Hopf bifurcation in RBC with rotation.

Robert Behringer, Duke University, *Fri., 11:25-12:10,* Stress Propagation in Granular Materials: Granular materials present a host of challenging questions at the most basic level. In dense granular materials, complex force structures, known as force chains dominate the transmission of force. Competing models to describe force propagation include purely diffusive, elastic, and wave-like behavior. One way to address the issue of how stresses propagate is to carry out experimental determinations of the Green's function, i.e. the response of a material to a local force perturbation. We have recently carried out such measurements using 2D photoelastic particles that allow us to determine the local force at the particle scale. These measurements indicate that the ensemble-averaged response depends significantly of the amount of order in the packing. In highly ordered packings, the response is consistent with a wave-like propagation of forces, whereas in disordered packings, the response is elastic. Notably, any given realization is typically complex, with large deviations from the ensemble-averaged response. When dense materials are deformed, the stress chains break and reform, leading to large-scale fluctuations. In Couette shear experiments, we have found that there is a novel transition with second-order-like properties as the density of the sample is varied. Conventional Coulomb models for stresses in shearing materials indicate that the forces should be independent of shear rate. However, we have recently found a slow dependence on shear rate that is not accounted for by conventional models.

Andrew Belmonte^1, Michael J. Shelley^2, Shaden T. Eldakar^1, and Chris H. Wiggins^2, *Sat., 2:45-3:05,* Dynamic Patterns of a Driven Hanging Chain: Swinging, Jumping, Knots: When shaken periodically at one end, a hanging chain or string displays a startling variety of distinct dynamic behaviors, depending on its length and the amplitude and frequency of the shaking. We find experimentally that instabilities occur in tongue-like regions of parameter space. The unstable states observed include swinging and rotating pendular motion, and also more complex, chaotic states. Mathematically, the dynamics are described by a nonlinear wave equation. Linear stability analysis predicts instabilities within the well-known resonance tongues; their boundaries agree well with our experiment. Full numerical simulations of the 3D dynamics reproduce and elucidate many aspects of the experiment, indicating for instance that the kinetic energy of the entire chain is periodically zero in the pendular state, and that sharp gradients in tension occur in the complex states. Experimentally the chain is also observed to tie knots in itself, some quite complex, which modify its subsequent dynamics; however the trefoil knot does not remain tied, but slips off the free end. These occurrences are beyond the reach of the current analysis and simulations.

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<u>Lora Billings</u> (Montclair State University), Ira Schwartz (Naval Research Laboratory), Erik Bollt (U.S. Naval Academy), *Fri., 11:05-11:25*, Noise Induced Chaos in Population Models: Population models are fascinating dynamical systems which capture all ranges of behavior, from periodic to chaotic time series. The SEIR model is a commonly used base model to predict epidemic outbreaks in many diseases. Our work is the first to identify the global mechanism to induce chaos by stochastic perturbations, or population noise, where it does not naturally occur. This mechanism combines both random fluctuations and global topology to create a stochastic version of a heteroclinic connection of the system. To refine the possibility of epidemic control, we have analyzed the stochastic transport between large and small outbreaks.

<u>Daniel Blair</u>, Arshad Kudrolli, *Sun., 5:00-5:20*, Self-Assembling Chains, Rings and Droplets in Dipolar Granular Fluids: We visualize the distinct phases of magnetized steel particles in a container vibrated along with non-magnetized particles that act as thermal carriers. Transition from a gas-like to a liquid-like phase is observed as the vibration amplitude is decreased. Clusters of magnetized particles are found to spontaneously self-assemble and grow as the surrounding free particles are exponentially depleted to a saturation value determined by the temperature and volume fraction. These clusters are initially extended chains that eventually coarsen into compact droplets with fractal dimension d = 1.5\pm 0.1. These experiments clarify the nature of clusters formed in the context of the dipolar hard sphere model. We also investigate the connection between clustering of dipolar hard spheres and the behavior of systems undergoing first order phase transitions.

<u>Harry Dankowicz</u>, Engineering Science and Mechanics, Virginia Tech, Blacksburg, VA, USA, Petri T Piiroinen, Dept. of Mechanics, Royal Institute of Technology, Stockholm, Sweden, *Sat., 3:55-4:15*, Exploiting Discontinuities for Stabilization of Recurrent Motions: A rigorous mathematical technique is presented for exploiting the presence of discontinuities in nonsmooth dynamical systems in order to control the local stability of periodic or other recurrent motions. The methodology is illustrated with examples from impacting systems, namely a model hopping robot, a Braille printer head, and a class of passive bipedal walkers. It is shown how initially strongly unstable motions can be successfully stabilized at negligible cost and without active energy injection.

Charles Doering, University of Michigan, *Sat., 2:00-2:45,* Limits on Turbulent Transport: Mathematical bounds on mass, momentum and heat transport for solutions of the incompressible Navier-Stokes and Boussinesq equations are reviewed. In some cases the scaling indicated by the bounds is (nearly) saturated by turbulent flows, but in some cases---most notably turbulent Rayleigh-Benard convection---there remains a large gap between experiments and the rigorous heat transport limits. We discuss some current research exploring these issues further.

Bruno Eckhardt and Erwan Hascoet, Fachbereich Physik, Philipps Universitat Marburg, 35032 Marburg, *Sun., 10:35-10:55,* Chaotic Advection in Oscillatory Flows: In a time-periodic but reversible flow trajectories return to their starting points and there can be no chaos. Experiments on 2-d flows with periodic and reversible driving forces (Gollub et al) do show chaos, and the question arises where reversibility is lost. We discuss two mechanisms: for small Reynolds number in the linear Stokes regime reversibility is lost by a viscous dephasing of the different spatial modes that enter the response of the fluid. For larger Reynolds numbers inertial effects dominate. We also show how reflection symmetries in the driving can prevent large scale transport.

Flavio Fenton and Steven Evans, Beth Israel Medical Center; Elizabeth Cherry and Harold Hastings, Hofstra University; Isabelle Banville and Richard Gray, University of Alabama, *Fri., 5:10-5:30,* Validation of Full 3D Numerical Simulations of Electrical Dynamics in Rabbit Ventricles with Experiments: Scroll waves of electrical activity in mammalian cardiac tissue have become a major focus of research because of their central role in arrhythmogenesis. We simulate the effects of two electromechanical-uncoupling drugs (DAM and CytoD) on the dynamics of sprial waves in ventricles using an existing 3D rabbit ventricular anatomical structure along with an ionic cell model based on experimentally measured mesoscopic electrophysiological properties of rabbit cells. As in experiments, we found that the use of DAM resulted mostly in stable tachycardia (single scroll waves) with a period of about 135 ms, while with CytoD more complex fibrillatory states were observed (multiple scroll waves). The difference in behavior between these two drugs can be explained in terms of the interaction between the ventricular structure and the electrical cell dynamics.

S. Julio Friedmann, Dept. of Geology, Univ. of Maryland, College Park, MD 20742, *Fri., 1:50-2:35,* Dynamics of Turbidity Currents: Gravity-driven Erosion and Deposition at the Edges of Continents: Turbidity currents are the primary agents of coarse-grained sediment transport across the continental slope and abyss. These are gravity currents which flow when sediment suspended in water is more dense than the ambient fluid (usually sea or lake water). As such, their behavior is very sensitive to changes in mass and momentum, which are functions of sediment concentration, grain-size distribution, current height, and gradient. The critical threshold of erosion is called "ignition", and produces rapid acceleration and bulking up to a maximum 10% sediment concentration at which point the primary suspension mechanism, turbulence, is damped. Below the ignition threshold, turbidity currents will decelerate and dampen to predicable termination. These strong positive and negative feedbacks can be indirectly measured in geological and experimental systems and the system dynamics qualitatively characterized. The relevant parameters can be collapsed to produce simple phase diagrams that help predict grain-size distributions, bed characteristics, pore volume connectivity, and behavioral response. Numerical, experimental, theoretical, and field-based studies will help to place quantitative constraints on system thresholds and response.

P. Grassberger, John von Neumann Institute for Computing, Juelich, Germany, *Sun., 8:30-9:30,* Nonlinear Time Series Analysis: This will be a general introduction, with emphasis on biomedical applications. After an introduction where the two paradigms of stochasticity and deterministic chaos are opposed, and several physiological examples are sketched, I'll start the more technical part by dicsussing time delay embeddings and choices of parameters for them. A first application will deal with noise reduction and signal separation based on the geometry of embeddings. Fetal heart beat extraction from a univariant ECG signal is discussed as a special case. We then discuss classical invariants (metric entropy, attractor dimension, Lyapunov exponents) and argue why using them as indicators for chaotic determinism is not very useful. The same should be true also for alternatives like false nearest neighbors or forecasting errors. In contrast we shall argue that strict determinism is not needed for the arsenal of nonlinear time series analysis to be useful. In contrast, I shall present evidence that effective "attractor" dimensions can be useful for predicting epileptic seizures and localizing epileptic foci. Finally we shall discuss various methods to study interdependencies between different time series. This includes cross correlation and coherence, mutual information, phase synchronization, and other interdependence measures. We shall discuss their usefulness in EEG analysis, in particular for epilepsy patients. Among these measures, of particular interest are asymmetric measures because they could, independent of time delays, indicate causal connections. Again this is illustrated with epileptic EEGs.

Jochen Cleve (MPIPKS Dresden), Thomas Dziekan (TU Dresden), Martin Greiner (Siemens Muenchen), *Sat., 5:00-5:20,* Reynolds Number Dependence of the Intermittency Exponent in Fully Developed Turbulence: The guiding principle for the inertial range dynamics of fully developed turbulence is scale invariance. The important question which are good fields and good observables for this has so far not attracted much attention. A careful analysis of hot-wire time series data reveals that velocity pdfs and structure functions do not reveal a strict scaling and that heuristic methods like Extended Self Similarity are misleading. It is the surrogate energy dissipation field together with two-point observables, like two-point correlators and cumulants, which show a clear and rigorous scaling, revealing that the intermittency exponent is a function of the Reynolds number. Once several observational effects are properly taken into account, empirical random multiplicative energy cascade models give a very satisfying description of these findings and allow for a unification of several data-driven models, which previously have appeared to be in conflict with each other.

Gemunu H. Gunaratne, ***Fri., 2:35-2:55***, **Development of Non-Invasive Diagnostics for Osteoporosis: A Model Based Approach:** The skeletal disease, osteoporosis, is a major socio-economic problem in an aging population. Optimal management of osteoporosis requires the availability of non-invasive diagnostics. Current research aimed at developing new diagnostic tools makes exclusive use of animal bones. Even preliminary tests to determine their suitability takes several years to design and implement. We have used a suitable model system to determine features of stress propogation in bone, and use the insight gained to identify possible forms for diagnostic tools. In particular, it is found that the ratio of linear responses to AC and DC strains acts as a surrogate for the strength of these systems. We are currently extending these studies to digitized images of bone samples.

Eric Heller, *Sat., 8:30-9:30,* Classical and Quantum Flow Over Hilly Terrain: Branching and Coherence: Recent experimental and theoretical work on the branching of electron flow under the influence of soft potential energy hills and valleys in nanostructures will be presented (Nature, March 8 2001). The work is applicable to a variety of situations involving propagation through random media, and represents perhaps a new regime in chaos theory. The cumulative effect of long range travel over many correlation lengths of the potential surprisingly leaves strong, preferred branches of flow intact. The combination of such flow with billiard walls will be discussed. Theoretical foundations and quantum implications will be presented.

Craig S. Henriquez, Ph.D. and W.H. Gardner Jr. Associate Professor of Biomedical Engineering and Computer Science, Duke University, *Fri., 4:25-5:10, I*ntegrative Modeling of the Heart: Studying the Dynamics of Atrial Fibrillation: The promise of computational biology is that it provides an enhanced ability to relate changes at the molecular level to changes in macroscopic function. But as with all techniques, computational modeling and simulation involve making significant tradeoffs, usually compromising realism to maintain tractability. In this talk, I will discuss the challenges of both creating and analyzing large scale, biologically realistic models of atrial fibrillation and explore some of the reasons why simulation and experimentation must come closer together to fully elucidate the dynamics of wavefront conduction in inhomogeneous, three-dimensional domains.

Leo Kadanoff, work done by Michael Brenner, Peter Constantin, Todd Dupont, Leo Kadanoff, Albert Libchaber, Sidney Nagel, Robert Rosner, and many others, *Mon., 8:30-9:30, M*aking a Splash; Breaking a Neck: The Development of Complexity in Physical Systems: We study the motion of fluids, with the aim of developing a fundamental understanding of fluid flow. Our program is characterized by close cooperation among experimenters, theoreticians, and simulators. The world about us exhibits many beautiful and important fluid flows. Consider clouds and waves, storms, and earthquakes, sunspots andmountain-building. What can we learn from all this richness? Mostly our work involves solving particular problems, e.g. 'how does heat flow in a pot of water heated over a flame'. But, in following these problems we soon get to broader issues: predictability and chaos, the likelihood of very extreme outcomes, and the natural formation of complex 'machines'. In the end, we try to ask if there is a 'science of complexity' and are there natural 'laws' of complex things. My answer is 'no', but I do see important lessons to be learned from studying such systems.

Lev Kaplan, University of Washington, *Sat., 10:35-10:55,* Wave Function Structure, Ergodicity, and Localization in Quantum Chaotic Systems: We discuss recent progress in the study of quantum wave functions and transport in classically ergodic systems. Surprisingly, short-time classical dynamics leaves permanent imprints on long-time and stationary quantum behavior, imprints that are absent from the long-time classical motion. These imprints can lead to fine-scale quantum behavior that differs greatly from random matrix theory expectations. Robust and quantitative predictions are obtained using semiclassical methods. Applications include wave structure on a disordered lattice, distribution of tunneling rates in an open system, structure of many-body fermion systems with random 2-body interactions, and the Coulomb blockade conductance peak distribution in quantum dots.

Henry Abarbanel, Matthew Kennel, Lupcjo Kocarev, Lucas Illing, *Sun., 9:30-9:50,* Estimating Parameters and Model Transformations by Chaotic Synchronization: We attack the problem of finding parameter values in an ordinary differential equation model whose solution best matches another model output or a given time series. By formulating the problem as a unidirectionally coupled system of oscillators, we show that generalized synchronization intrinsically regularizes what is typically be a highly ill-conditioned least-squares optimization problem for chaotic dynamics. This enables powerful standard optimizing algorithms to search the parameter space efficiently with explicitly computable gradients. Additionally we allow a general static nonlinear transformation from the space of the original source to fitted model whose parameters also may be estimated simultaneously with the vector field. One application is to validate an empirical or semi-empirical small model as a suitable replacement for a first-principles complex model, for instance a low-degree of freedom model of a neuron which is a faithful dynamical replica of a very complex first-principles Hodgkin-Huxley neuron.

Herb Levine, *Fri., 8:30-9:30,* Biological Applications of Pattern-Formation Physics: In the past several decades, physicists have made great strides in understanding how spatial patterns can arise in systems driven far from equilibrium. Of course, many important issues and significant challenges remain. But, with this sense of progress, many researchers began addressing the question of whether the study of pattern formation could help elucidate the formation of structure in biological systems, often called morphogenesis. Of course, living matter is much more complex than non-living. Yet, this talk will hopefully convince you that not only is this physics-based approach possible, but is in fact extremely promising. There are many processes one could choose to discuss; for definiteness, I will focus on the life cycle of the soil amoeba Dictyostelium discoideum. In this organism, starvation triggers a day-long series of transformations that take solitary amoebae and create a cooperative multicellular organism; the process culminates in a plant-like fruiting body containing spore cells specialized for survival in harsh conditions. Ideas from the physics of pattern formation have been used to help explain the wave field used for cell guidance, the streaming of cells into the aggregate and the collective motions seen in multicellular stages. Currently, several groups are working on the single-cell chemotactic response from a similar perspective.

Rene' Mikkelsen, Michel Versluis, Devaraj van der Meer, Ko van der Weele, and Detlef Lohse, *Sun., 2:45-3:05*, Granular Eruptions: Void Collapse and Jet Formation: A steel ball dropped onto loose, very fine sand creates an upward jet exceeding the release height of the ball. It is generated by the gravity-driven collapse of the void created by the ball: the focused pressure pushes the sand straight up into the air. Using a 2-dimensional experimental setup and high-speed imaging, the collapse of the void is visualized. For high impact velocities the void collapse is seen to entrain air. These experimental observations are accounted for within a Rayleigh-Plesset type model. The entrained air bubble slowly rises through the sand, and upon reaching the surface causes a granular eruption.

Linda J. Moniz, University of Maryland, James A. Yorke, University of Maryland, *Mon., 9:50-10:10*, Convergence of Dynamically Defined Upper Bound Sets: We develop a rigorous formalism for a computational theory for finding various sets important to the dynamics of a map. We develop a novel approach to locating basin boundaries and arbitrary isolated invariant sets. Our comprehensive theory also covers a number of published results. Examples of these include periodic orbits, chain-recurrent sets, and maximal invariant sets. We begin by describing "upper-bound sets", that is, sets that contain the desired set. In our theory, each upper-bound set is a collection of grid boxes. We give conditions which guarantee that as precision and resolution increase, the upper-bound sets converge to (shrink down to) the desired set. We describe a measure of closeness of particular upper-bound sets to the sets they contain. We prove that our implementation of the theory for C^{2} maps achieves, in the sense of the measure, the closest possible upper-bound sets of this type.

Jean-Francois Pinton, Laboratoire de Physique, Ecole Normale Superieure de Lyon (France), pinton@ens-lyon.fr, *Sat., 4:15-5:00*, Statistics of Lagrangian Velocity in Fully Developed Turbulence: The understanding of the dynamics of turbulent flows has been a major goal for fundamental and applied fluid dynamics research for almost a century now. On the fundamental side, turbulence is the head figure of a non-linear dissipative system with a very large number of degrees of freedom. On the applied side, the properties of turbulent flows govern the dispersion of pollutants, the physics of mixing, etc. In very recent years, analytical and numerical studies have shown that progress can be made by analyzing the flow properties in the reference frame of a moving fluid particle (the Lagrangian viewpoint), instead of considering the velocity field at a fixed point in space (the Eulerian viewpoint). In order to completely address turbulence in the Lagrangian frame, one needs to describe the dynamics over the entire range of scales of motion. We have developed such technique, based on sonar principles, to measure directly the velocity of individual small tracer particles over long times. We have analyzed the statistics of the Lagrangian velocity of single particles for flows with turbulent Reynolds numbers between 100 and 1100. We observe that the Lagrangian spectrum has a Lorentzian form in agreement with a Kolmogorov-like scaling in the inertial range. The probability density function (PDF) of the velocity time increments displays a change of shape from quasi-Gaussian a integral time scale to stretched exponential tails at the smallest time increments. This intermittency, when measured from relative scaling exponents of structure functions, is more pronounced than in the Eulerian framework. Another important observation is that in the erratic course of the particle motion, infinitesimal changes of velocity occur with `random' decorrelated directions but with a correlation of magnitude which persists over the longest times of the flow. Using an analogy with the properties of Multifractal Random Walks, we propose that this feature is essential in the development of intermittency in turbulence.

Thomas R. Powers, Annemarie J. Van Parys, and Kenneth S. Breuer, Division of Engineering, *Fri., 9:30-9:50,* Brown University, Bacterial Flagellar Mechanics: In bacterial chemotaxis, cells such as E. coli drift up chemical gradients by means of a directed random walk. Near the beginning of each step of a walk, the rotating helical flagella which propel the cell form a bundle. Using slender-body theory, we show that the counter-rotation of the cell body necessary for torque balance is sufficient to wrap the flagella into a bundle, even in the absence of the swirling flows produced by each individual flagellum. Using macroscopic experiments, we also study the viscous flows set up by two rotating helices and their role in bundling.

Mark Raizen, *Sat., 9:50-10:35,* Observation of Chaos Assisted Tunneling of Ultra-Cold Atoms: We study quantum dynamics of ultra-cold cesium atoms in mixed phase space consisting of islands of stability surrounded by chaos. We use a new method to prepare a minimum uncertainty wavepacket located on one island in phase space. We observe coherent tunneling oscillations between this state and a symmetry related island. We show that this system exhibits chaos assisted tunneling as characterized by the participation of the intermediate stochastic sea, the sensitivity to parameters, and the enormous enhancement in the tunneling rate between distant states.

Paul So, Ernest Barreto, Kresimir Josic, Evelyn Sander, and Steven J. Schiff, *Sun., 3:05-3:25,* Limits to the Experimental Detection of Nonlinear Synchrony: Chaos synchronization is often characterized by the existence of a continuous function between the states of the components. However, in coupled systems without inherent symmetries, the synchronization set might be extremely complicated. For coupled invertible systems, the synchronization set can be nondifferentiable; in the more severe case of coupled noninvertible systems, the synchronization set will in general be a multivalued relation. We will discuss how existing methods for detecting synchronization will be hampered by these features.

J.M. Ortiz de Zarate, Depto de Fisica Aplicada I, Universidad Complutense, E28040 Madrid, Spain, J.V. Sengers, Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742, U.S.A., ***Mon., 11:00-11:20,*** **Fluctuations in Fluids in Thermal Nonequilibrium States Below the Convective Rayleigh-Benard Instability:** Starting from the linearized fluctuating Boussinnesq equations we derive an expression for the structure factor of fluids in stationary convection-free thermal nonequilibrium states, taking into account both gravity and finite-size effects. It is demonstrated how the combined effects of gravity and finite size cause the structure factor to go through a maximum value as a function of the wave number q. The appearance of this maximum is associated with a crossover from a q**-4 dependence for larger q to a q**2 dependence for small q. The relevance of this theoretical result for the interpretation of light scattering and shadowgraph experiments is elucidated. The relationship with studies of various aspects of the problem by other investigators will be discussed. The paper thus provides a unified treatment for dealing with fluctuations in fluid layers subjected to a stationary temperature gradient regardless of the sign of the Rayleigh number R, provided that R is smaller than its critical value associated with the appearance of Rayleigh-Benard convection.

E. Sharon, B. Roman, S. G. Shin, M. Marder and H. L. Swinney, ***Mon., 10:10-10:30,*** **Multi-scale Buckling in Thin Sheets:** We present an experimental study of the buckling process, which follows the tearing of plastic sheet. The irreversible plastic flow around the crack tip creates a new, curved metric in the sheet. This metric is smooth and all its components are either constant (in the propagation direction) or monotonically increasing (towards the sheet's edge). Despite this monotonic behavior the sheet buckles and forms a cascade of waves, superimposed on each other, with highly separated wavelengths. We show that all the members of the cascade are similar and thus create a fractal, which spans over 2.5 decades. The problem has two relevant length scales: The sheet thickness t and the plastic zone radius Rp, which provide the lower and upper bounds for the possible wavelengths. Though t<<Rp, one can not take the limit t=0 keeping only Rp as a single length scale. Instead, t remains the relevant parameter for the bending energy associated with the buckling and sets an energy threshold for the buckling at all scales. This point is demonstrated by showing that the wavelengths of each buckling cascade scale linearly with the sheet thickness t. We suggest that this multi-scale buckling cascade is a general phenomenon that should appear whenever a thin sheet posses a curved metric, which cannot be matched by buckling in a single wave number. Under these conditions the sheet forms many "local solutions", each of them matches the metric over a different scale. Their superposition constructs the global solution, which matches the metric at all scales and thus minimizes the energy. We support this suggestion by performing molecular dynamics simulations of a thin elastic sheet with a similar metric. The simulations show the formation of a buckling cascade similar to the one observed in experiments. Finally we show that similar buckling patterns are very common in nature. We can find them in flowers, leafs and living tissues. We suggest that these very complex surfaces are not necessarily the results of highly complex growth mechanism. Instead, they might result from very simple processes, which create non-flat metrics.

David Sweet, Andamooka and Parvez Guzdar, Institute for Research in Electronics and Applied and Physics (IREAP), University of Maryland, *Sat., 5:20-5:40,* Fractal Dimension Of Chaotic Saddles in the Kuramoto-Sivashinski Equation: We study the fractal dimension of chaotic saddles -- invariant sets of initial conditions in phase space responsible for chaotic transient motion -- in the Kuramoto-Sivashinski equation, a 1D PDE that models the turbulent propagation of a flame front, thin, viscous fluid flow down an inclined plane, and other physical systems. This PDE can be approximated by a very-high dimensional dynamical system (e.g., 64, 128, or more dimensions) to which a numerical algorithm recently introduced in [D. Sweet, H. E. Nusse, J. A. Yorke, Phys. Rev. Lett. 86 2261 (2001)] may be applied to efficiently compute orbits closely approximating orbits on chaotic saddles present in the systems phase space. A novel simulation method allows these computations to be performed on a PC rather than a supercomputer.

Harry L. Swinney, University of Texas at Austin, *Mon., 12:05-12:50,* Scaling in Two-dimensional and Three-dimensional Rotating Turbulent Flows*: In three-dimensional (3D) turbulent flow, vortices stretch axially and fold, but this process cannot occur in two dimensions. While all turbulent flows are 3D on sufficiently small scales, atmospheric and oceanic flows are approximately 2D on large scales. We study turbulence in a rotating tank where the flow becomes 2D for sufficiently rapid rotation rate (by the Taylor-Proudman theorem), while for low rotation rates the flow is 3D [1]. We find that for 2D turbulence the probability distribution function (PDF) for the difference in velocity between two points is independent of the separation r between the two points, i.e., the flow is self-similar. In contrast, the PDFs for 3D turbulence are gaussian for large r and exponential for small r. We further compare the 2D and 3D turbulence flows by determing structure function scaling exponents and by applying the beta and gamma tests of the hierarchical structure model; these quantities will be defined and discussed. The conclusion is that 2D turbulence in a rotating flow is surprisingly intermittent, but the intermittency is a consequence of large coherent vortices rather than the stretching and folding of vortex lines as in 3D.*Supported by ONR, [1] C.N. Baroud, B.P. Plapp, Z.S. She, and H. L. Swinney, submitted.

Sandra M. Troian, Princeton University, *Sun., 4:15-5:00,* On a Generalized Approach to Linear Stability of Spatially Dependent Thin Film Flows: Recent interest in microscale flows, which can sustain exceedingly large surface to volume ratios, has focused attention on the use of normal or shear force actuation to effect liquid migration along a solid surface. For instance, a thin liquid film supported on a differentially heated substrate will spontaneously flow toward the cooler end in a process known as thermocapillary forcing. In another example, a film contacted by a non-uniform distribution of surface active material will rapidly flow toward the uncontaminated end under the action of Marangoni stresses. Such spreading films typically undergo fingering instabilities at the advancing front which resemble either a series of parallel liquid rivulets or highly ramified dendritic structures. During the past several years, we have used a combination of experiment and theoretical modeling in an effort to provide a unified framework describing the stability characteristics of these and related thin film flows. The presence of capillary, thermocapillary, Marangoni or van der Waals stresses in free surface films creates spatially (and temporally) dependent interface shapes. The linearized operators governing disturbances in film thickness or concentration are therefore typically non self-adjoint. A consequence of this feature is that conventional modal analysis can only describe the asymptotic behavior of these systems. A rigorous description of the early and intermediate behavior requires a transient growth study. This type of analysis not only identifies the growth rate of optimal disturbances but reveals their initial and evolved waveform shape at all times. Strongly non-normal operators can introduce the possibility of severe disturbance amplification and subsequent non-linear coupling. In this presentation, we outline the transient growth behavior and amplification of optimal disturbances for thermocapillary driven flows. Time permitting, we review Marangoni driven systems as well. We examine the pseudospectral behavior of the associated disturbance operators and illustrate why transient growth studies offer a more suitable probe of the stability of free surface thin film flows.

Hakan E. Tureci, H.G.L. Schwefel, A.D. Stone, N.B. Rex and R.K. Chang, *Sat., 9:30-9:50,* Chaos Brought to Light: Microcavity Lasers: It has been shown that micro-cavity lasers represent a realization of a wave-chaotic system which presents many unsolved problems for optical physics. These systems can be classified as "refractive billiards", where a phase space approach is particularly rewarding. In the past, various mode geometries have been observed in such micro-lasers: whispering gallery modes, bow-tie modes and square-modes based on periodic orbits which are either stable or marginally stable. Recently, on a GaN based micro-laser, a scarred mode was found to lase, which is based on an unstable triangular periodic orbit. I will report our analysis of this experiment, and some recent experiments based on polymer samples, which demonstrate further evidence for the fertility of a phase-space approach.

Jeff Urbach, Alexis Prevost, *Fri., 2:55-3:15,* Georgetown University Distributions and Correlations in a Vibrated Granular Layer: Recent results from an experimental investigation of the dynamics of a layer of uniform metallic spheres on a horizontal plate that is oscillating vertically are reported. We have investigated the role of the forcing by comparing the behavior of the layer on a rough plate to that on a flat plate. In the fully fluidized regime the spatial correlations of the granular fluid on either plate are indistinguishable from an analogous equilibrium fluid at the same density. The velocity distributions are also similar, but differ significantly from the equilibrium fluid. Also unlike the equilibrium system, significant velocity correlations are observed in both cases, but their form is strongly dependent on the forcing.

Devaraj van der Meer, Ko van der Weele, and Detlef Lohse Department of Applied Physics and J.M. Burgers, Centre for Fluid Dynamics, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands, *Fri., 3:45-4:05,* Birth and Sudden Death of a Granular Cluster: Granular gases spontaneously separate into dense and dilute regions. Here it is experimentally and theoretically demonstrated that the cluster formation and its breakdown are fundamentally different due to the lack of time reversibility: For a vibro-fluidized granular gas in N connected compartments the cluster formation takes place gradually, via several metastable states, whereas the collapse of the cluster is very abrupt. The observed cluster lifetime (as a function of the driving intensity) is analytically calculated within a flux model, making use of the self-similarity of the process. After collapse, the cluster diffuses out into the uniform distribution with an anomalous diffusion exponent 1/3.

Brian DiDonna, University of Pennsylvania; Bob Geroch, University of Chicago; Eric Kramer, Simon's Rock College; Shankar Venkataramani, University of Chicago; Tom Witten, University of Chicago, *Sun., 5:20-5:40,* Crumpled Sheets : A Paradigm for Multiple Scale Behavior in Nonlinear Systems: I will give an (elementary) overview of some of the mathematical questions that arise in the multiple scale analysis of nonlinear systems and illustrate these questions with examples relating to crumpled sheets. I will then discuss some of the tools and techniques that are used to study this problem. Finally, I will give my (very biased) perspective on some of the recent results that have been obtained, and comment on the relevance of these results to other multiple-scale problems.

Lawrie Virgin, *Sat., 3:05-3:25,* Transient Global Behavior in Experimental Nonlinear Oscillators: This talk is concerned with the determination of basin boundaries in experimental nonlinear oscillators. Global transient behavior has received considerable attention in numerical studies but is relatively unexplored from an experimental perspective, despite the fact that a global view of transient behavior provides a much more complete description of the dynamics of a system than a traditional concentration on steady-state behavior. Five different experimental systems are considered: four mechanical and one electrical.

Greg Voth, Haverford College, George Haller, Brown Unversity, Jerry Gollub, Haverford College and Univ. of Pennsylvania, *Sun., 3:55-4:15,* Measurements of Stretching Fields in Chaotic Mixing Experiments: Using precision measurements of tracer particle trajectories in a two-dimensional fluid flow producing chaotic mixing, we directly measure the time-dependent stretching field. This quantity, which was previously available only numerically, attains local maxima along lines that coincide with the stable and unstable manifolds of hyperbolic fixed points of Poincare maps. Dye concentration fields are measured in the same flow as the stretching fields, and we demonstrate the way that lines of fluid points that have recently experienced large stretching coincide with contours of the dye concentration. We also explore the probability distribution of stretching and applications to the prediction of mixing rates.

Jane Wang, *Fri., 9:50-10:35,* Unsteady Aerodynamics of Insect Flight: The myth `bumble-bees can not fly according to conventional aerodynamics' simply reflects our poor understanding of unsteady viscous fluid dynamics. In particular, we lack a theory of vorticity shedding due to dynamic boundaries at the intermediate Reynolds numbers relevant to insect flight, typically between 10^2 and 10^4, where both viscous and inertial effects are important. In our study, we compute unsteady viscous flows, governed by the Navier-Stokes equation, about a two dimensional flapping wing which mimics the motion of an insect wing. I will present two main results: the existence of a preferred frequency in forward flight and its physical origin, and 2) the vortex dynamics and forces in hovering dragonfly flight. If time permits, I will show the recent results on comparing our computational results against robotic fruitfly experiments and modeling three dimensional flapping flight driven by muscles.

Eric Weeks, *Mon., 9:30-9:50,* Aging in Colloidal Glasses: Aging is the slow evolution of a nonequilibrium material, and occurs in metals, glasses, and granular media. We directly observe the aging of a colloidal glass using confocal microscopy. Slight relaxations in the aging sample involve small regions of rearranging particles, and the time scale for these relaxations increases as the age of the sample increases. We attempt to describe these rearrangements and their origin, to provide a real-space picture of the dynamics of aging.

Jeffrey B. Weiss, Program in Atmospheric and Oceanic Sciences, University of Colorado, Boulder, *Sun., 2:00-2:45,* A Dynamical Systems View of Planetary Turbulence: The turbulence of planetary atmospheres and oceans self-organizes into a spatio-temporal pattern of coherent structures such as vortices and jets. These structures provide insight into the long-standing problem of reducing fluid turbulence to a chaotic dynamical system. The attractor of the turbulence is an evolving population of structures, and the structures' degrees of freedom are the reduced coordinate system which describe the attractor. These ideas are explored in a hierarchy of systems with increasing complexity, from Hamiltonian ordinary differential equations to oceanic observations.

Matthew Bennett(1), Heidi Rockwood(2), Mike Schatz(1), and Kurt Wiesenfeld(1), *Fri., 4:05-4:25,* Huygens' Clocks: In 1665, Christiaan Huygens described a "strange sympathie" between two of his pendulum clocks. Those of us who study nonlinear coupled oscillators are fond of quoting Huygens' observation as the first example of spontaneous synchronization. The clocks always fell into an antiphase motion. We decided to revisit Huygens' clocks experimentally and theoretically (we also got someone to translate the Latin for us!). In the end, we reached a pretty satisfactory understanding of the effect. It turns out that in order to observe the phenomenon required both great talent and a fair amount of luck. (1) School of Physics, Georgia Tech, (2) Department of Modern Languages, Georgia Tech

George M. Zaslavsky, Department of Physics and Courant Institute of NYU, *Sun., 9:50-10:35,* Tracers, Coherent Structures, and Fractional Kinetics: We consider chaotic dynamics of tracers in a system of point vortices and, in parallel, the phase space topology of the vortices. There exist a specific connection between coherent structures of the vortex system and tracers transport , which is possible to describe in an analytical way and confirm by simulations. The coherent structures occur as clusters of few vortices, which impose the tracers kinetics of the fractional type. On that way a characteristic exponent of the tracers dispersion can be obtained from the first principles.