# APS March Meeting 2013

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# Wednesday, March 20, 2013 8:00AM - 11:00AM –

Session M39 DFD: Drops, Bubbles, and Interfacial Fluid Mechanics I 348 - Sidney R. Nagel, University of Chicago

### 8:00AM M39.00001 Condensed droplet jumping: Capillary to inertial energy transfer

RYAN ENRIGHT, Bell Labs Ireland, Alcatel-Lucent, NENAD MILJKOVIC, Massachusetts Institute of Technology, MICHAEL MORRIS, CRANN, University College Cork, EVELYN WANG, Massachusetts Institute of Technology — When condensed droplets coalesce on a superhydrophobic nanostructured surface, the resulting droplet can jump from the surface due to the release of excess surface energy. This behavior has been shown to follow a simple inertial-capillary scaling. However, questions remain regarding the nature of the energy conversion process linking the excess surface energy of the system before coalescence and the kinetic energy of the jumping droplet. Furthermore, the primary energy dissipation mechanisms limiting this jumping behavior remain relatively unexplored. In this work, we present new experimental data from a two-camera setup capturing the trajectory of jumping droplets on nanostructured surfaces with a characteristic surface roughness length scale on the order of 10 nm. Coupled with a model developed to capture the main details of the bridging flow during coalescence, our findings suggest that: 1. the excess surface energy available for jumping is a fraction of that suggested by simple scaling due to incomplete energy transfer, 2. internal viscous dissipation is not a limiting factor on the jumping process at droplet sizes on the order of 10 $\mu$m and 3. jumping performance is strongly affected by forces associated with the external flow and fields around the droplet. This work suggests bounds on the heat transfer performance of superhydrophobic condensation surfaces.

### 8:12AM M39.00002 How does an air film evolve into a bubble during drop impact?

, JI SAN LEE, BYUNG MOOK WEON, JUNG HO JE, Pohang University of Science and Technology, KAMEL FEZZAA, Argonne National Laboratory — When a liquid drop impacts on a solid substrate, a tiny air film is generally entrapped between the drop and the substrate and eventually evolves into a bubble by surface energy minimization. We investigated how air evolves into a bubble during drop impact using ultrafast x-ray phase-contrast imaging that enables us to track the detailed morphological changes of air with high temporal and spatial resolutions. We found that the evolution takes place through complicated three stages: inertial retraction of the air film, contraction of the top air surface into a toroidal bubble, and pinch-off of a daughter droplet inside the bubble. The collapse and the pinch-off can be explained by energy convergence that is associated with Ohnesorge number (Oh) regarding capillary waves and viscous damping. We measured a critical Oh number, Oh* $\sim 0.026 \pm 0.003$, above which the generation of the daughter droplet is suppressed. Interestingly we found that the bubble is detached favorably from wettable surfaces, which suggests a feasible way to eliminate bubbles for many applications by controlling surface wettability. The threshold angle for bubble detachment was measured as $\sim 40 \pm 5^\circ$ for water, which agrees with a geometrical estimation.

### 8:24AM M39.00003 Swirls and splashes: air vortices created by drop impact

, IRMGARD BISCHOFBERGER, KELLY W. MAUSER, ANDRZEJ LATKA, SIDNEY R. NAGEL, University of Chicago — A drop impacting a solid surface with sufficient velocity will splash and emit many small droplets. While liquid and substrate properties are clearly important for determining the splashing threshold, it has been shown that removing the ambient air suppresses splashing completely [1]. However, the mechanism underlying how the surrounding gas affects splashing remains unknown. As has been recently shown, there is no air beneath the liquid that could cause the splash [2] – thus where does the air matter? We use modified Schlieren optics combined with high-speed video imaging to visualize the air vortices created by the rapid spreading of the drop after it hit the substrate. In the first moments after impact, these vortices remain bound to the spreading drop, creating a low-pressure zone that travels with the advancing lamella. At a later time, after the occurrence of the splash, the vortices detach from the drop. We discuss possible connections between the forces generated by the vortices on the liquid lamella and the initiation of a splash. [1] L. Xu, W. W. Zhang and S. R. Nagel, Phys. Rev. Lett. 94, 184505 (2005) [2] M. M. Driscoll and S. R. Nagel, Phys. Rev. Lett. 107, 154502 (2011)

### 8:36AM M39.00004 Stability of electrically charged toroidal droplets in a viscous liquid.

, ALEXANDROS FRAGKOPOULOS, EKAPOP PAIRAM, ALBERTO FERNANDEZ-NIEVES, Georgia Institute of Technology — Droplets and bubbles are spherical due to surface tension. As a result, making non spherical droplets and understanding their evolution is a challenge. Nevertheless, we were able to develop a method to generate toroidal droplets in a viscous liquid and study their stability. Recently, we have extended this method to generate charged toroidal droplets suspended in an electrically insulating and highly viscous liquid, and have studied the evolution of these droplets subject to constant charge or constant voltage constraints. In this talk I will be presenting the initial results on the stability of charged toroidal droplets.

### 8:48AM M39.00005 Clapping wet hands: dynamics of a fluid curtain

, BRIAN CHANG, Virginia Tech, BRICE SLAMA, Ecole Polytechnique, France, RANDALL GOODNIGHT, SEAN GART, SUNGHWAN JUNG, Virginia Tech — Droplets splash around when a fluid volume is quickly compressed. This has been observed during common activities such as kids clapping with wet hands. The underlying mechanism involves a resting fluid volume being compressed vertically between two objects. This compression causes the fluid volume to be ejected radially, thereby generating fluid ligaments and droplets at a high speed. In this study, we designed and performed experiments to observe the process of ligament and drop formation while a fluid is squeezed. A thicker rim at the outer edge forms and moves after the squeezing, and then becomes unstable and breaks into smaller drops. We compared experimental measurements with theoretical models over three different stages; early squeezing, intermediate ejection, and later break-up of the fluid. We found that drop spacing set by the initial capillary instability does not change in the course of rim expansion; consequently final ejected droplets are very sparse compared to the size of the rim.

### 9:00AM M39.00006 Electric Charging Effects on Condensed Droplet Jumping

, NENAD MILJKOVIC, DANIEL J. PRESTON, MIT, RYAN ENRIGHT, Bell Labs Ireland, RONG YANG, KAREN K. GLEASON, EVELYN N. WANG, MIT — When condensed droplets coalesce on a superhydrophobic surface, the resulting droplet can jump due to the conversion of surface energy into kinetic energy. This frequent out-of-plane droplet jumping has the potential to enhance condensation heat transfer. Furthermore, for more than a century, researchers have shown that droplet-surface interactions can be dominated by electrostatic charge buildup. In this work, we studied droplet jumping dynamics on nanostructured copper oxide and carbon nanotube surfaces coated with tri-chloro silane and PFDA hydrophobic coatings, respectively. Through analysis of droplet trajectories and terminal velocities under various electric fields (0 – 50 V/cm), we show that condensation on these surfaces having both conducting and insulating substrates results in a buildup of positive surface charge ($H^+$) due to dissociated water ion adsorption on the superhydrophobic coating. Consequently, an accumulation of the opposite charge ($OH^-$) occurs on the condensing droplet interface, which creates an attractive force between the jumping droplet and the condensing surface. Using this knowledge, we demonstrate a novel condensation mechanism whereby an external electric field is used to oppose the droplet-surface attraction, further enhancing the coalescing droplet jumping frequency and overall surface heat transfer.

**9:12AM M39.00007 Dynamics of a Disturbed Sessile Drop Measured by Atomic Force Microscopy**[1] , PATRICIA MCGUIGGAN, SAMUEL ROSENTHAL, ANDREA PROSPERETTI, Johns Hopkins University — A new method for studying the dynamics of a sessile drop by atomic force microscopy (AFM) is demonstrated. A hydrophobic microsphere (radius, r $\sim$ 20 - 30 $\mu$m) attached to an AFM cantilever is brought into contact with a sessile water drop. Immediately after the initial rise of the meniscus, the microsphere oscillates about a fixed average position while partially immersed in the liquid. The small ($<$ 100 nm) oscillations of the interface are readily measured with AFM. The oscillations correspond to the resonance oscillation of the entire droplet. Although the microsphere volume is 6 orders of magnitude smaller than the drop, it excites the normal resonance modes of the liquid interface. Resonance oscillation frequencies were measured for drop volumes between 5 and 200 $\mu$L. The results for the two lowest normal modes are quantitatively consistent with continuum calculations for the natural frequency of hemispherical drops with no adjustable parameters. The method may enable sensitive measurements of volume, surface tension, and viscosity of small drops.

[1]This material is based on work supported by the 3M Nontenured Faculty Grant and the National Science Foundation (NSF) under Grant CMMI-0709187.

**9:24AM M39.00008 How leaves survive falling raindrops** , SEAN GART, KATIE NORRIS, DANIEL CHIQUE, SUNGHWAN JUNG, Virginia Tech — Plant surfaces found in nature often exhibit hydrophobic or hydrophilic wetting properties; a particular example is the surface of leaves. Most leaves are compliant enough to survive while being impacted by rain droplets. Here, we investigate this leaf-drop system exhibiting a unique system of coupled elasticity and drop dynamics. By replacing the leaf with a thin piezoelectric cantilever beam, we further measure and harvest this drop kinetic energy as a workable model for an energy-harvester from rain drops.

**9:36AM M39.00009 The Vibrating Vapor Layer Beneath a Leidenfrost Drop** , THOMAS CASWELL, JUSTIN BURTON, SIDNEY NAGEL, University of Chicago — The levitation of a liquid drop above a hot surface is known as the Leidenfrost effect. Due to strong evaporation, a vapor layer forms beneath the drop that both levitates and thermally insulates the liquid, resulting in extremely long drop life times. The geometry of this vapor layer has been characterized using high-speed laser-light interference imaging [1], which showed spatial oscillations of the interface. Here we report the evolution of these oscillations using an algorithm we developed for identifying the interference fringes. From these fringes we extract the relative height profile of the vapor layer. We track the time evolution of the spatial-fluctuations and measure the absolute change in the average height of the drop over a time scale of seconds. Large, transient, azimuthal deformations to the bottom of the drop are correlated with the rapid escape of vapor and a change in height above the surface. We also observe and characterize a range of metastable star-like oscillations in the shape. [1] Burton et al., PRL 109, 074301 (2012).

**9:48AM M39.00010 Coalescence of Two Drops Surrounded by an Outer Fluid** , JOSEPH PAULSEN, RÉMI CARMIGNIANI, ANERUDH KANNAN, JUSTIN BURTON, SIDNEY NAGEL, University of Chicago — When two liquid drops make contact, a liquid bridge forms and then rapidly expands due to surface-tension forces that are divergent at the point where the drops first touch. This nonlinear process has received a lot of recent attention, especially for two liquid drops coalescing in vacuum or air. However, little is known about how the surrounding fluid influences the singularity when the two drops are surrounded by an external fluid with significant density or dynamic viscosity. We use a combination of high-speed imaging and an ultrafast electrical method to study coalescence in this regime. We find that even if the outer fluid is over 10 times more viscous than the fluid within the drops, the coalescence speed need not be affected, even near the singularity. In order to understand the nature of the flows in the surrounding fluid, we also study the limiting case of air bubbles coalescing inside a very viscous external liquid.

**10:00AM M39.00011 Measurement of Bubble Size Distribution Based on Acoustic Propagation in Bubbly Medium**[1] , XIONGJUN WU, CHAO-TSUNG HSIAO, JIN-KEUN CHOI, GEORGES CHAHINE, Dynaflow Inc. — Acoustic properties are strongly affected by bubble size distribution in a bubbly medium. Measurement of the acoustic transmission becomes increasingly difficulty as the void fraction of the bubbly medium increases due to strong attenuation, while acoustic reflection can be measured more easily with increasing void fraction. The ABS Acoustic Bubble Spectrometer®©, an instrument for bubble size measurement that is under development tries to take full advantage of the properties of acoustic propagation in bubbly media to extract bubble size distribution. Properties of both acoustic transmission and reflection in the bubbly medium from a range of short single-frequency bursts of acoustic waves at different frequencies are measured in an effort to deduce the bubble size distribution. With the combination of both acoustic transmission and reflection, assisted with validations from photography, the ABS Acoustic Bubble Spectrometer®© has the potential to measure bubble size distributions in a wider void fraction range.

[1]This work was sponsored by Department of Energy SBIR program

**10:12AM M39.00012 Experimental and Numerical Investigation of Pressure Wave Attenuation due to Bubbly Layers**[1] , ARVIND JAYAPRAKASH, TIFFANY FOURMEAU, CHAO-TSUNG HSIAO, GEORGES CHAHINE, Dynaflow Inc., DYNAFLOW INC. TEAM — In this work, the effects of dispersed microbubbles on a steep pressure wave and its attenuation are investigated both numerically and experimentally. Numerical simulations were carried out using a compressible Euler equation solver, where the liquid-gas mixture was modeled using direct numerical simulations involving discrete deforming bubbles. To reduce computational costs a 1D configuration is used and the bubbles are assumed distributed in layers and the initial pressure profile is selected similar to that of a one-dimensional shock tube problem. Experimentally, the pressure pulse was generated using a submerged spark electric discharge, which generates a large vapor bubble, while the microbubbles in the bubbly layer are generated using electrolysis. High speed movies were recorded in tandem with high fidelity pressure measurements. The dependence of pressure wave attenuation on the bubble radii, the void fraction, and the bubbly layer thickness were parametrically studied. It has been found that the pressure wave attenuation can be seen as due to waves reflecting and dispersing in the inter-bubble regions, with the energy absorbed by bubble volume oscillations and re-radiation. Layer thickness and small bubble sizes were also seen as having a strong effect on the attenuation with enhanced attenuation as the bubble size is reduced for the same void fraction.

[1]This study was supported by the Department of Energy, under SBIR Phase II Contract DE-FG02-07ER84839.

**10:24AM M39.00013 Bubble Augmented Propulsor Mixture Flow Simulation near Choked Flow Condition**[1] , JIN-KEUN CHOI, CHAO-TSUNG HSIAO, GEORGES CHAHINE, Dynaflow, Inc. — The concept of waterjet thrust augmentation through bubble injection has been the subject of many patents and publications over the past several decades, and computational and experimental evidences of the augmentation of the jet thrust through bubble growth in the jet stream have been reported. Through our experimental studies, we have demonstrated net thrust augmentation as high as 70%for air volume fractions as high as 50%. However, in order to enable practical designs, an adequately validated modeling tool is required. In our previous numerical studies, we developed and validated a numerical code to simulate and predict the performance of a two-phase flow water jet propulsion system for low void fractions. In the present work, we extend the numerical method to handle higher void fractions to enable simulations for the high thrust augmentation conditions. At high void fractions, the speed of sound in the bubbly mixture decreases substantially and could be as low as 20 m/s, and the mixture velocity can approach the speed of sound in the medium. In this numerical study, we extend our numerical model, which is based on the two-way coupling between the mixture flow field and Lagrangian tracking of a large number of bubbles, to accommodate compressible flow regimes. Numerical methods used and the validation studies for various flow conditions in the bubble augmented propulsor will be presented.

[1]This work is supported by Office of Naval Research through contract N00014-11-C-0482 monitored by Dr. Ki-Han Kim.

### 10:36AM M39.00014 Dynamics of a Cylindrical Bubble between Two Parallel Plates for Biomedical Applications

, SOWMITRA SINGH, JIN-KEUN CHOI, GEORGES CHAHINE, Dynaflow, Inc. — Microbubbles have been shown to produce directional and targeted membrane poration of individual cells in microfluidic systems, which could be of use in ultrasound-mediated drug and gene delivery. To study and understand the mechanisms at play in such interactions, a full three- dimensional Boundary Element Method (BEM) has been developed to describe complex bubble deformations, jet formation, and bubble splitting. The present work aims at providing analytical validation for the three-dimensional BEM code, 3DynaFS©, when the dynamics of a bubble between two parallel plates is studied. The analytical equations of a cylindrical (2-D) bubble between two flat plates were derived without accounting for any shape deformation. Comparisons between the analytical model and the numerical model were carried out in scenarios where the shape of an expanding/collapsing bubble between two parallel plates is nearly cylindrical (large maximum equivalent bubble radius to plate gap ratio). Interestingly, both the analytical and the numerical methods predict a strong dependence of the bubble period on the plate size.

### 10:48AM M39.00015 Universality Results for Multi-phase Hele-Shaw Flows[1]

, PRABIR DARIPA, Texas A&M University, College Station, Texas — Saffman-Taylor instability is a well known viscosity driven instability of an interface separating two immiscible fluids. We study linear stability of displacement processes in a Hele-Shaw cell involving an arbitrary number of immiscible fluid phases. This is a problem involving many interfaces. Universal stability results have been obtained for this multi-phase immiscible flow in the sense that the results hold for arbitrary number of interfaces. These stability results have been applied to design displacement processes that are considerably less unstable than the pure Saffman-Taylor case. In particular, we derive universal formula which gives specific values of the viscosities of the fluid layers corresponding to smallest unstable band. Other similar universal results will also be presented. The talk is based on the following paper.

[1] Prabir Daripa and Xueru Ding, "Universal Stability Properties for Multi-Layer Hele-Shaw Flows and Application to Instability Control," *SIAM Journal of Applied Mathematics*, Vol 72, No. 5, pp. 1667-1685, 2012.

[1]This work was supported by the Qatar National Research Fund (a member of The Qatar Foundation).

# Wednesday, March 20, 2013 11:15AM - 1:51PM –

## Session N39 DFD: Drops, Bubbles, and Interfacial Fluid Mechanics II 348 - Patricia McGuiggan, Johns Hopkins University

### 11:15AM N39.00001 Multimode Multidrop Serial Coalescence Effects during Condensation on Two-Tier Superhydrophobic Surfaces[1]

, KONRAD RYKACZEWSKI, ADAM T. PAXTON, SUSHANT ANAND, MIT, XUEMEI CHEN, ZUANKAI WANG, City University of Hong Kong, KRIPA K. VARANASI, MIT — Mobile coalescence leading to spontaneous drop motion was initially reported to occur only during water condensation on two-tier superhydrophobic surfaces (SHS), consisting of both nanoscale and microscale topological features. However, subsequent studies have shown that mobile coalescence also occurs on solely nanostructured SHS. Thus, recent focus has been on understanding the condensation process on just nanostructured surfaces rather than on two-tier SHS. Here, we investigate the impact of microscale topography of two-tier SHS on the droplet coalescence dynamics and wetting states during the condensation process. We identify new droplet shedding modes, which consist of serial coalescence events that lead to merging of multiple droplets. The formed drops either depart or remain anchored to the surface. We explain the observed post-merging drop adhesion trends through direct correlation to formation of drops in nanoscale as well as microscale Wenzel and Cassie-Baxter wetting states. We find that optimally designed two-tier SHS, which promote the highest number of departing microdrops, consists of microscale features spaced close enough to enable transition of larger droplets into micro-Cassie state, yet at the same time provide sufficient area in-between the features for occurrence of mobile coalescence.

[1]This work was funded by NSF and the Dupont-MIT Alliance and was in part performed using facilities at NIST.

### 11:27AM N39.00002 Elasticity of the contact line for droplets on anisotropic superhydrophobic surfaces

, MARCO RIVETTI, ANAIS GAUTHIER, JEREMIE TEISSEIRE, ETIENNE BARTHEL, CNRS - Saint Gobain — We present an experimental and numerical investigation on the receding of contact line for water droplets on glass superhydrophobic surfaces. In particular, we focus our attention on surfaces textured with anisotropic lattice posts. We measure that the receding contact angle is not affected by the anisotropy of the lattice. This surprising behavior is closely related to the elastic deformations of the contact line which can be by studied by direct observation. We interpret this phenomenon in term of propagation of kink defects along the lattice. We detail the influence of the morphology of the lattice on the propagation of kinks, as well as the importance of the shape of the posts. Three dimensional numerical simulations confirm that kinks are the key ingredient for the comprehension of the receding contact angle.

### 11:39AM N39.00003 Dynamics of condensation on lubricant impregnated surfaces

, SUSHANT ANAND, ADAM PAXSON, KONRAD RYKACZEWSKI, Massachusetts Institute of Technology, DANIEL BEYSENS, UMR CNRS-ESPCI ParisTech, KRIPA VARANASI, Massachusetts Institute of Technology — Replacing the filmwise condensation mode with dropwise condensation promises large improvements in heat transfer that will lead to large cost savings in material, water consumption and decreased size of the systems. In this regards, use of superhydrophobic surfaces fabricated by texturing surfaces with nano/microstructures has been shown to lead decrease in contact line pinning of millimetric drops resulting in fast shedding. However, these useful properties are lost during condensation where droplets that nucleate within texture grow by virtue of condensation to large sized droplets while still adhering to the surface. Recently we have shown that liquid impregnated surfaces can overcome many limitations of conventional superhydrophobic surfaces during condensation. Here we discuss aspects related to condensation on lubricant surfaces, such as behavior of growing droplets. We compare the characteristics of droplets condensing on these surfaces with their behavior on conventional un-impregnated superhydrophobic surfaces and show how use of lubricant impregnated surfaces may lead to large enhancement in heat transfer and energy efficiencies.

### 11:51AM N39.00004 Contact Angle Hysteresis of Photo-Responsive Materials[1]

, SAMUEL ROSENTHAL, PATRICIA MCGUIGGAN, Johns Hopkins University — An atomic force microscope (AFM) is used to measure the meniscus force on individual microspheres coated with photo-responsive materials such as anatase and rutile $TiO_2$, azobenzene, and other doped oxides as they contact and are retracted from an air/water interface. By exposing the coated microspheres to UV light, the contact angle change. The change can be detected by measuring the increase in the meniscus force. Exposure to visible, infrared, or far infrared light – as the specific material requires - reverses the contact angle change. The measured force-distance curves are fitted to macroscopic wetting theory. From these measurements, the contact angle, the contact angle hysteresis, and the position of the contact line pinning were simultaneously determined. This allowed for a quantification of the contact angle changes from photo-switching.

[1]NSF CMMI-0709187

## 12:03PM N39.00005 Thermodynamic Model for Contact Angle Hysteresis on Rough Surfaces

, RISHI RAJ, Device Research Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology, RYAN ENRIGHT[1], Stokes Institute, University of Limerick, SOLOMON ADERA, EVELYN WANG, Device Research Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology — Wettability of solid surfaces can be tuned by introducing roughness. This effect has been explained by Wenzel, whereby texturing increases the degree of hydrophilicity (hydrophobicity) of an intrinsic hydrophilic (hydrophobic) flat surface. However, experimentally observed dynamic contact angles deviate significantly from those predicted by Wenzel equation. In this work, we demonstrate that local contact line distortion and pinning on structured surfaces is the key aspect that needs to be accounted for in the dynamic droplet models. Contact line distortions and pinning were visualized and analyzed to develop a thermodynamic model for contact angle hysteresis on rough surfaces. The developed model showed good agreement with the experimental advancing and receding contact angles, both at low and high solid fractions. The thermodynamic model was further extended to demonstrate its capability to capture droplet shape evolution during liquid addition and removal in our experiments and those in literature. The understanding developed in this study offers new insight extending the fundamental understanding of solid-liquid interactions required for the design of advanced functional coatings for microfluidics, biological, manufacturing, and heat transfer applications.

[1]Previously: Device Research Laboratory, Department of Mechanical Engineering, Massachusetts Institute of Technology

## 12:15PM N39.00006 Wetting Transition of Water

, SERAH FRIEDMAN, MATT KHALIL, PETER TABOREK, University of California, Irvine — Pure liquid water does not wet most solid surfaces. Liquid water on these surfaces beads up and forms droplets with a finite contact angle. General thermodynamic principles suggest that as the temperature approaches the critical point, the contact angle should go to zero, marking the wetting transition. We have made an optical cell which can operate near the critical point of water (Tc=373C, Pc=217 atm) to study this phenomenon on sapphire, graphite and silicon. We have used two methods to measure the wetting temperature of water on these surfaces. Firstly, we studied a single droplet on a horizontal surface and optically measured the change in contact angle as a function of increasing temperature. Second, we studied the condensation of droplets on a vertical plate as a function of temperature. As the temperature approached the wetting temperature in both cases, the droplets spread and eventually form a smooth film along the surface of the plate. The wetting temperature on sapphire is near 240C and is considerably higher on graphite. Our observed values of Tw are significantly higher than the predictions made by the sharp-kink approximation and recent molecular dynamics simulations.

## 12:27PM N39.00007 Moving Water Droplets on Aluminum and Copper Surfaces Using Surface Tension Gradients

, MUIDH ALHESHIBRI, NATHANIEL ROGERS, ANDREW SOMMERS, KHALID EID, Miami University — The behavior of water droplets on metal surfaces is very important for many applications, especially in heat exchangers in air conditioning and refrigeration. We use photolithography and/or shadow masks to create alternating hydrophobic/hydrophilic Cu micro-channels on an aluminum surface and to move water droplets on the surface. The contact angle that is formed between water droplets and the surface is clearly asymmetrical due to the different surface properties at the contact line between the droplets and the patterned surface. An HDFT self-assembled mono-layer allows for a large change in the water droplet contact angle on the copper, but seems to have no effect on the aluminum surface. We will show our results on the effect of the surface patterning and surface roughness on water droplet behavior. We also demonstrate that the engineered surface gradients cause water droplets to travel more than 1" on a horizontal or upward tilted surface.

## 12:39PM N39.00008 Atomistic simulations of surfactant adsorption kinetics[1]

, EUGENIYA ISKRENOVA, Propulsion Directorate, Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433, USA and UES, Inc., Dayton, OH 45432, USA, SOUMYA PATNAIK, Propulsion Directorate, Air Force Research Laboratory, Wright Patterson Air Force Base, OH 45433, USA — Enhancing heat transfer is an important and challenging problem in a variety of industrial and technological applications including aircraft thermal management. Nucleate pool boiling is recognized as one of the most efficient methods to enhance heat transfer. Describing the plethora of multi-physics phenomena involved in nucleate pool boiling requires developing a multiscale model aimed at not only advancing our understanding but also at providing insights into the mechanisms for control and prediction of heat transfer in boiling. Adding surfactants to boiling water has been experimentally observed to enhance or inhibit the heat transfer depending on the surfactant concentration and chemistry. On a molecular level, addition of surfactants leads to the development of dynamic surface tension and changes in interfacial and transfer properties, thus contributing to the complexity of the multiscale model. We present an atomistic modeling study of the interfacial adsorption kinetics of aqueous surfactant systems at a range of concentrations at room and boiling temperature. Large scale classical molecular dynamics simulations were used to study the surfactant kinetics and estimate the adsorption and desorption rates at liquid-solid and liquid-vacuum interfaces.

[1]The authors acknowledge the funding from AFOSR Thermal Science Program and AFRL DSRC for computer time and resources.

## 12:51PM N39.00009 Small Scale Evaporation Kinetics of a Binary Fluid Mixture

, CARL BASDEO, DEZHUANG YE, DEVENDRA KALONIA, TAI-HSI FAN, University of Connecticut, MECHANICAL ENGINEERING TEAM, PHARMACEUTICAL SCIENCES COLLABORATION — Evaporation induces a concentrating effect in liquid mixtures. The transient process has significant influence on the dynamic behaviors of a complex fluid. To simultaneously investigate the fluid properties and small-scale evaporation kinetics during the transient process, the quartz crystal microbalance is applied to a binary mixture droplet of light alcohols including both a single volatile component (a fast evaporation followed by a slow evaporation) and a mixture of two volatile components with comparable evaporation rates. The density and viscosity stratification are evaluated by the shear wave, and the evaporation kinetics is measured by the resonant signature of the acoustic p-wave. The evaporation flux can be precisely determined by the resonant frequency spikes and the complex impedance. To predict the concentration field, the moving interface, and the precision evaporation kinetics of the mixture, a multiphase model is developed to interpret the complex impedance signals based on the underlying mass and momentum transport phenomena. The experimental method and theoretical model are developed for better characterizing and understanding of the drying process involving liquid mixtures of protein pharmaceuticals.

## 1:03PM N39.00010 Red blood cell in simple shear flow

, WEI CHIEN, Dept. of Physics, National Taiwan University, Taipei 106, Taiwan, YAYU HEW, Dept. of Physics,U. Texas-Arlington, TX, USA, YENG-LONG CHEN, Inst. of Physics, Academia Sinica, Taipei 11529, Taiwan — The dynamics of red blood cells (RBC) in blood flow is critical for oxygen transport, and it also influences inflammation (white blood cells), thrombosis (platelets), and circulatory tumor migration. The physical properties of a RBC can be captured by modeling RBC as lipid membrane linked to a cytoskeletal spectrin network that encapsulates cytoplasm rich in hemoglobin, with bi-concave equilibrium shape. Depending on the shear force, RBC elasticity, membrane viscosity, and cytoplasm viscosity, RBC can undergo tumbling, tank-treading, or oscillatory motion. We investigate the dynamic state diagram of RBC in shear and pressure-driven flow using a combined immersed boundary-lattice Boltzmann method with a multi-scale RBC model that accurately captures the experimentally established RBC force-deformation relation. It is found that the tumbling (TU) to tank-treading (TT) transition occurs as shear rate increases for cytoplasm/outer fluid viscosity ratio smaller than 0.67. The TU frequency is found to be half of the TT frequency, in agreement with experiment observations. Larger viscosity ratios lead to the disappearance of stable TT phase and unstable complex dynamics, including the oscillation of the symmetry axis of the bi-concave shape perpendicular to the flow direction. The dependence on RBC bending rigidity, shear modulus, the order of membrane spectrin network and fluid field in the unstable region will also be discussed.

**1:15PM N39.00011 Non-laminar motion of biological suspension: an illustration for blood cell passing a 3-micrometer capillary**[1] , IAT NENG CHAN, University of Macau — Discovering in video images of blood cell motion, a new concept is developed for cell passing a tight capillary that has a large difference compared to the published simulation results. In video image the deformation of moving blood cell shows abnormal pressure from cell membrane under highly contacted condition with capillary wall. Moreover, when the cell struggles through the narrow capillary the appearance of additional force to assist the cell motion is necessary. In more detail analysis, the flow motion in capillary displaying a non-laminar pattern which is obviously different to that shows in a nearby larger capillary on the same image, can be explained as a non-regular flow described by an equivalent flow companied with sink and source. Using this illustration with the calculated volumes for normal and deformed cells, the flow speed and pressure are derived to compare with the best known results and also to the calculated flow speed from the images. After compared to diffusion effect, the exchange rate of materials in the flow and the efficiency factor to the circulatory system can be estimated.

[1]Funded by the research grant of the University of Macau

**1:27PM N39.00012 Stability of a falling viscous sheet** , CLAUDE PERDIGOU, University Paris 6, GILLES PFINGSTAG, Saint Gobain Recherche Aubervilliers, BASILE AUDOLY, University Paris 6 and CNRS, AREZKI BOUDAOUD, Ecole Normale Superieure de Lyon and CNRS — Falling films can be found in various processes of the food, glass and polymer industry. We study thin viscous films flowing vertically under the action of gravity, when poured from a slit. The lateral sides are unconstrained and the stretching effect of gravity induces a narrowing of the film in the horizontal direction, by Poisson's effect. This leads to compressive stress for some range of parameters, and we study the associated viscous buckling instabilities. A local stability analysis is used to characterized the flow parameters leading to potential instabilities. A global stability analysis is carried out, and an eigenvalue problem is solved numerically. This is implemented using the finite-element method with high order derivatives.

**1:39PM N39.00013 A Different Cone: Bursting Drops in Solids** , XUANHE ZHAO, Duke University — Drops in fluids tend to be spheres—a shape that minimizes surface energy. In thunderstorm clouds, drops can become unstable and emit thin jets when charged beyond certain limits. The instability of electrified drops in gases and liquids has been widely studied and used in applications including ink-jet printing, electrospinning nano-fibers, microfluidics and electrospray ionization. Here we report a different scenario: drops in solids become unstable and burst under sufficiently high electric fields. We find the instability of drops in solids morphologically resembles that in liquids, but the critical electric field for the instability follows a different scaling due to elasticity of solids. Our observations and theoretical models not only advance the fundamental understanding of electrified drops but also suggest a new failure mechanism of high-energy-density dielectric polymers, which have diverse applications ranging from capacitors for power grids and electric vehicles to muscle-like transducers for soft robots and energy harvesting.

# Wednesday, March 20, 2013 2:30PM - 5:06PM –

## Session R39 DFD: Pattern Formation and Nonlinear Dynamics 348 - Gregory Eyink, Johns Hopkins University

**2:30PM R39.00001 The Peierls Transport Equation — Revised** , YI-KANG SHI, GREGORY EYINK, Johns Hopkins University — In 1929 Peierls derived an equation for the joint probability distribution of all wave amplitudes in classical and quantum anharmonic systems, still widely used in quantum transport theory, plasma physics and weak wave turbulence. For uncorrelated amplitudes, it implies the kinetic equation for the wave spectrum/occupation numbers. This equation was rederived by Brout & Prigogine (1956), Zaslavskii & Sagdeev (1967), and recently by Choi et al. (2005) in wave turbulence. We show that these derivations are non-systematic, retaining terms smaller than those neglected. We obtain an equation simpler than Peierls', which still implies the kinetic equation and also a generalized kinetic equation for the distribution of single-mode amplitudes, previously obtained by Choi et al. We show by an H-theorem that the single-mode distributions approach Gaussian, if this equation is valid for all amplitudes. Non-Gaussian statistics can arise if the equation breaks down for large amplitudes/strong nonlinearity. This may explain intermittency observed in laboratory experiments of weak turbulence. Moreover, we show the most general solutions of our revised Peierls equations are statistical ensembles of chaotic solutions of kinetic equations, or "super-turbulence", another source of intermittency.

**2:42PM R39.00002 Controlling the position of traveling fronts** , JAKOB LÖBER, HARALD ENGEL, ECKEHARD SCHÖLL, Institute for Theoretical Physics, TU Berlin — We present a method to control the position as a function of time of a one-dimensional traveling front solution of a one-component reaction-diffusion system according to a specified protocol of movement. Given this protocol, the control function is found as the solution of a perturbatively derived integral equation. Two cases are considered. First, we derive an analytical expression for the space $(x)$ and time $(t)$ dependent control function $f(x,t)$ valid for arbitrary protocols and arbitrary bistable reaction kinetics. These results for the control agree well with results of an optimal control algorithm. Second, for stationary control the integral equation reduces to a Fredholm integral equation of the first kind. For the Schlögl model, we present an analytical solution of the problem to stop a front at a specified position. All analytical results are in good agreement with numerical simulations of the underlying reaction-diffusion equations. Extensions to two spatial dimensions and other equations supporting traveling wave solutions are considered.

**2:54PM R39.00003 Experimental studies of stationary reaction fronts in a chain of vortices with imposed wind**[1] , TOM SOLOMON, CARLEEN BOYER, Bucknell University — We present experiments that study the behavior of the excitable Belousov-Zhabotinsky (BZ) reaction in a chain of alternating vortices with an imposed uniform wind. Previous experiments[2] have shown that fronts in this system are pinned for a wide range of imposed wind speeds, propagating neither forward against the wind nor in the downwind direction. We explain this behavior with a recent theory[3] that proposes the existence of *burning invariant manifolds* (BIMs) that act as local barriers to front propagation. Fronts are pinned when a BIM or a combination of BIMs spans the width of the vortex chain, blocking the reaction front. We show experimental measurements of the shape of the pinned front for a range of different wind speeds, and compare these shapes to the BIMs calculated theoretically. We also consider the dependence of the front shape on the location of the initial trigger for the front.

[1]Supported by NSF Grants DMR-0703635, DMR-1004744, and and PHY-1156964.
[2]M.E. Schwartz and T.H. Solomon, Phys. Rev. Lett. **100**, 028302 (2008).
[3]J. Mahoney, D. Bargteil, M. Kingsbury, K. Mitchell and T. Solomon, Europhys. Lett. **98**, 44005 (2012).

**3:06PM R39.00004 Pinning of reaction fronts by burning invariant manifolds in spatially-disordered fluid flows**[1] , MAYA NAJARIAN[2], TOM SOLOMON, Bucknell University — We present experiments on the pinning of reaction fronts in spatially-disordered fluid flows with an imposesd wind. The disordered flow is driven by a magnetohydrodynamic forcing technique, and there is a uniform wind imposed on the flow with the use of a translation stage. Reaction fronts are produced using the excitable Belousov-Zhabotinsky chemical reaction. For a wide range of wind speeds, a complicated stationary front forms, pinned to the underlying vortex flow, neither propagating forward against the wind nor being blown backwards. The shape of the front depends significantly on the magnitude of the imposed wind. We propose that the shape of the stationary front is determined by a collection of overlapping BIMs that act as barriers against forward movement of the reaction front. The location of the BIMs can be predicted by integrating a three-dimensional set of ordinary differential equations[3] that describes the dynamics of an element of an evolving reaction front in the fluid flow.

[1]Supported by NSF Grants DMR-0703635, DMR-1004744, and PHY-1156964.

[2]Current address: Middlebury College

[3]J. Mahoney, D. Bargteil, M. Kingsbury, K. Mitchell and T. Solomon, Europhys. Lett. **98**, 44005 (2012).

**3:18PM R39.00005 Laboratory Scale Simulating of Strange Spiral Plumes in Fluid with Hight Ptandtl Number** , ALBERT SHARIFULIN, Perm State Technical University, ANATOLY POLUDNITSIN, Perm State University — We experimentally investigated the appearance of a plumes from local hot spot and study its interaction with cellular flow in closed cavity filled by silicon oil with Prandtl number $\mathrm{Pr} \approx 2 \cdot 10^3$. Convective plume generated by a local heat source, located on the top of the small rubber cylinder, which is located in the center of the bottom of the rectangular cell. To simulate the hot-spot green laser has been used. Roll-type large-scale convective flow was generated by heating of the one vertical sides of cavity. Influence of power of hot point on the shape of plume has been investigated. It is shown that the presence of cellular convective motion may lead to the formation of a strange spiral convective plume. This plume looks like Archimedes spiral replaced on vertical plane. Physical mechanism of the formation of strange spiral plume and application of obtained results for mantle convection problems are discussed.

**3:30PM R39.00006 Double-diffusive layers adjacent to cold chimney flows during transient mushy-layer growth** , JIN-QIANG ZHONG, TongJi University, Shanghai, China, QIWEI XUE, JOHN WETTLAUFER, Yale University, NewHaven, CT, USA — We examine the cooling effect of chimney flows in the liquid region during transient upward growth of a mushy layer in solidifying aqueous ammonium chloride. Through drainage channels in a mushy layer, cold, relatively fresh fluid is carried into the warm, salt-stratified liquid region. Double-diffusive cells form due to the cooling effect of the chimney flows and evolve into a series of downwelling horizontal layers. Using shadowgraph methods and dyed fluids we demonstrate the vigorous flow circulations and compositional mixing within each layer. Vertical concentration and temperature profiles reveal the double-diffusive staircase structure across the layers. The downward velocity of the layers decreases as they approach to the mush-liquid interface, which is interpreted by a filling-box model representing the momentum and compositional transport of turbulent continuous plumes in a confined region. The present experiment provides insight to evaluate the solute fluxes from growing mushy layers.

**3:42PM R39.00007 Connectivity-disorder effect on collective synchronization** , JAEGON UM, School of Physics, Korea Institute for Advanced Study, Seoul 130-722, Korea, HYUNSUK HONG, Department of Physics, Chonbuk National University, Jeonju 561-756, Korea, HYUNGGYU PARK, School of Physics, Korea Institute for Advanced Study, Seoul 130-722, Korea — We investigate a system of random frequency oscillators coupled through sparse random networks and explore connectivity-disorder effects on collective synchronization. In particular, we pay attention to how the random quenched disorder in connectivity affects the nature of synchronization transitions. The oscillator frequencies are assigned independently from an unimodal, bimodal, or uniform distribution. Extensive numerical simulations as well as the mean-field analysis have been performed on Erdös-Rényi random networks. We find that the quenched connectivity disorder invalidates the mean-field prediction of distinctive transition natures depending on frequency distributions in random networks. In fact, the same continuous synchronization transition is found for all types of frequency distributions. The physical origin of this unexpected result is discussed.

**3:54PM R39.00008 Geometry of branching stream networks** , HANSJORG SEYBOLD, ROBERT YI, ALEX PETROFF, OLIVIER DEVAUCHELLE, DANIEL ROTHMAN, MIT — River networks have been a source of fascination for centuries. Yet, how these networks form and create these geometries remains elusive. Recently we have shown that streams branching in a diffusive field bifurcate at a characteristic angle of $\alpha = 2\pi/5 = 72^\circ$. This result is obtained from Lowner dynamics by combining classical results of groundwater hydrology with the hypothesis that streams grow in the direction of maximal water flux into the channel's tip. Our theoretical results are umambigously consistent with field measurements we conducted in a 100 km$^2$ channel network on the Florida Panhandle. Here we extend our theory to include slope effects and apply our analysis to large drainage basins. We hypothesize that the extension of the network at the tip is driven by a diffusive process leading to a (slope corrected) $2\pi/5$ branching at the leaves of the network.

**4:06PM R39.00009 Absence of power-law scaling in the dendritic crystal growth of ammonium chloride** , ANDREW DOUGHERTY, Lafayette College — We report measurements of the dendritic crystal growth of $NH_4Cl$ from supersaturated aqueous solution at small supersaturations, with a goal of understanding the origin of the sidebranching structure. The early detection of sidebranches requires measurements of small deviations from the smooth steady state shape, but that underlying shape is not precisely known at the intermediate distances relevant for sidebranch measurements. We find that no simple power law describes the average crystal shape, the average sidebranch amplitude, or the average sidebranch envelope. Instead, the effective power law exponents appear to increase steadily as a function of distance from the dendritic tip. Comparisons of the amplitude of sidebranches with that predicted by models of noise-driven sidebranching require careful measurements of materials parameters such as the capillary length. Previous published estimates for this material varied by over a factor of 20. We report new measurements of the capillary length and find $d_0 = 0.224 \pm 0.005$ nm. Based on those new measurements, we find that the amplitude of the sidebranches in this system is larger than expected from numerical models.

**4:18PM R39.00010 ABSTRACT WITHDRAWN —**

**4:30PM R39.00011 Multistable dynamics in electroconvecting liquid crystals** , ZRINKA GREGURIC FERENCEK, JOHN CRESSMAN, George Mason University — Nonlinear driven system can exhibit a diverse range of dynamics, from highly ordered to chaotic. These systems are ubiquitous, from atmospheric phenomena to brain function. Here we study such dynamics in electroconvecting liquid crystals. There applied electric fields create structured roll-like patterns that support the creation, evolution, and annihilation of defects in the rolls. By using a time scale separation algorithm based on diffusion map delay coordinates we have been able to identify a small number of multistable dynamics in this system. We utilize perturbations to control or steer the system between these different dynamics. We will discuss how this method of identification and interaction can be utilized to better interact with a wide range of dynamic systems.

### 4:42PM R39.00012 Coherent Pattern Prediction in Swarms of Delay-Coupled Agents[1] , LUIS MIER-Y-TERAN-ROMERO, Johns Hopkins University/Naval Research Laboratory, ERIC FORGOSTON, Department of Mathematical Sciences, Montclair State University, IRA SCWARTZ, U.S. Naval Research Laboratory, Nonlinear Systems Dynamics Section, Plasma Physics Division — We consider a general swarm model of self-propelling particles interacting through a pairwise potential in the presence of a fixed communication time delay. Previous work has shown that swarms with communication time delays and noise may display pattern transitions that depend on the size of the coupling amplitude. We extend these results by completely unfolding the bifurcation structure of the mean field approximation. Our analysis reveals a direct correspondence between the different dynamical behaviors found in different regions of the coupling-time delay plane with the different classes of simulated coherent swarm patterns. We derive the spatio-temporal scales of the swarm structures, and also demonstrate how the complicated interplay of coupling strength, time delay, noise intensity, and choice of initial conditions can affect the swarm. In addition, when adding noise to the system, we find that for sufficiently large values of the coupling strength and/or the time delay, there is a noise intensity threshold that forces a transition of the swarm from a misaligned state into an aligned state. We show that this alignment transition exhibits hysteresis when the noise intensity is taken to be time dependent.

[1]Office of Naval Research, NIH (LMR and IBS) and NRL (EF)

### 4:54PM R39.00013 Structure-Property Relationships for Branched Worm-Like Micelles , GREGORY BEAUCAGE, DURGESH RAI, University of Cincinnati — Micellar solutions can display a wide range of phase structure as a function of counter ion content, surfactant concentration, and the presence of ternary components. Under some conditions, common to consumer products, extended cylindrical structures that display persistence and other chain features of polymers are produced. These worm-like micelles (WLMs) can form branched structures that dynamically change under shear and even in quiescent conditions. The rheology of these branched WLMs is strongly dependent on migration of the branch points, and the dynamics of branch formation and removal. Persistence and other polymer-based descriptions are also of importance. We have recently developed a scattering model for branched polyolefins and other topologically complex materials that can quantify the branching density, branch length, branch functionality and the hyperbranch (branch-on-branch) content of polymers. This work is being extended to study branching in WLMs in work coupled with Ron Larson at UMich to predict rheological properties.

## Wednesday, March 20, 2013 2:30PM - 5:30PM – Session R47 DFD: Invited Session: Simulation of Interfaces in Two-Fluid Flows Hilton Baltimore Holiday Ballroom 6 - Shahriar Afkhami, New Jersey Institue of Technology

### 2:30PM R47.00001 Accelerated boundary integral simulations of particulate and two-phase flows , ANNA-KARIN TORNBERG, Royal Institute of Technology (KTH) — In micro-fluidic applications where the scales are small and viscous effects dominant, the Stokes equations are often applicable. The suspension dynamics that is observed already with rigid particles and fibers are very complex also in this Stokesian regime, and surface tension effects are strongly pronounced at interfaces of immiscible fluids. Simulation methods can be developed based on boundary integral equations, which leads to discretizations of the boundaries of the domain only, and hence fewer unknowns compared to a discretization of the PDE. Two main difficulties associated with boundary integral discretizations are to construct accurate quadrature methods for singular and nearly singular integrands, as well as to accelerate the solution of the linear systems, that will have dense system matrices. If these issues are properly addressed, boundary integral based simulations can be both highly accurate and very efficient. We will discuss simulations of periodic suspensions of rigid particles and rigid fibers in 3D, where the simulations are accelerated by a newly developed spectrally accurate FFT based Ewald method, as well as highly accurate simulations of many interacting drops in 2D.

### 3:06PM R47.00002 Direct Numerical Simulations of Multiphase Flows[1] , GRETAR TRYGGVASON, University of Notre Dame — Many natural and industrial processes, such as rain and gas exchange between the atmosphere and oceans, boiling heat transfer, atomization and chemical reactions in bubble columns, involve multiphase flows. Often the mixture can be described as a disperse flow where one phase consists of bubbles or drops. Direct numerical simulations (DNS) of disperse flow have recently been used to study the dynamics of multiphase flows with a large number of bubbles and drops, often showing that the collective motion results in relatively simple large-scale structure. Here we review simulations of bubbly flows in vertical channels where the flow direction, as well as the bubble deformability, has profound implications on the flow structure and the total flow rate. Results obtained so far are summarized and open questions identified. The resolution for DNS of multiphase flows is usually determined by a dominant scale, such as the average bubble or drop size, but in many cases much smaller scales are also present. These scales often consist of thin films, threads, or tiny drops appearing during coalescence or breakup, or are due to the presence of additional physical processes that operate on a very different time scale than the fluid flow. The presence of these small-scale features demand excessive resolution for conventional numerical approaches. However, at small flow scales the effects of surface tension are generally strong so the interface geometry is simple and viscous forces dominate the flow and keep it simple also. These are exactly the conditions under which analytical models can be used and we will discuss efforts to combine a semi-analytical description for the small-scale processes with a fully resolved simulation of the rest of the flow. We will, in particular, present an embedded analytical description to capture the mass transfer from bubbles in liquids where the diffusion of mass is much slower than the diffusion of momentum. This results in very thin mass-boundary layers that are difficult to resolve, but the new approach allows us to simulate the mass transfer from many freely evolving bubbles and examine the effect of the interactions of the bubbles with each other and the flow. We will conclude by attempting to summarize the current status of DNS of multiphase flows.

[1]Support by NSF and DOE (CASL)

### 3:42PM R47.00003 Advances and Challenges in Modeling Interfacial Flows , MARIANNE FRANCOIS, Los Alamos National Laboratory — Interfacial flows are multi-material flows comprised of two or more immiscible materials demarcated by interfaces. They are encountered in several applications of interest to the Department of Energy. Examples of applications include materials processing (e.g. casting), inertial confinement fusion and solvent extraction. We are interested in the development of accurate numerical methods to simulate with high-fidelity interfacial flows. For such simulation, the position of the interface and interface physics need to be predicted as part of the solution of the flow equations. One of the many techniques is known as the volume tracking method. It is a pure Eulerian method that represents the interface with volume fraction and intrinsically ensures mass conservation. In this talk, I will describe several advances that have been made over the past 25 years and discuss remaining challenges in the context of the volume tracking method.

### 4:18PM R47.00004 A moment of fluid method for computing solutions to multiphase/multimaterial flows , MARK SUSSMAN, Florida State University, Department of Mathematics — We combine the multimaterial Moment-of-Fluid (MOF) work of Ahn and Shashkov with the work of Kwatra et al for removing the acoustic time step restriction in order to solve multimaterial flows in which each material might be compressible or incompressible. The mass weights found in the algorithm of Kwatra et al are computed directly from the multimaterial MOF reconstructed interface. We treat the interface(s) between materials as sharp when discretizing the boundary conditions between materials. The combination of the multimaterial MOF reconstruction together with the cell centered formulation devised by Kwatra et al enable us to robustly compute multimaterial flows with large density ratios, stretching and tearing of interfaces and contact line dynamics at the junction of 3 materials with minimal volume fluctuation of each material (if a given material is incompressible). Simulations for multimaterial flows are presented with applications to combustion (atomization and spray) and microfluidics.

**4:54PM R47.00005 Direct numerical simulation of coaxial atomizing jets** , STEPHANE ZALESKI, Universite Pierre et Marie Curie Paris 6 — No abstract available.

# Thursday, March 21, 2013 8:00AM - 11:00AM –

## Session T16 GPC DFD: Climate Physics / Instabilities and Turbulence 318 - James Brasseur, Pennsylvania State University

**8:00AM T16.00001 Simultaneous measurement of sphericity and scattering phase functions from single atmospheric aerosol particles in Las Cruces, NM** , SEAN MARTIN, KEVIN APTOWICZ, West Chester University, YONG-LE PAN, US Army Research Laboratory, RICHARD CHANG, Yale University, RONALD PINNICK, US Army Research Laboratory — We report upon the collection of elastic light scattering patterns with high angular resolution and large angular coverage from single atmospheric aerosol particles in Las Cruces, NM. Radiative forcing due to aerosols is a primary source of uncertainty in climate models. Characterization of tropospheric aerosols is carried out by inversion of optical measurements made remotely by land-based instruments and satellites. An integral part of the retrieval procedure is accounting for particle shape (i.e. nonsphericity). In-situ and laboratory measurements of aerosol particles play a critical role in validating and constraining the inversion procedure used in climate models. In this work, we utilize high angular resolution and large angular coverage scattering patterns to simultaneously calculate particle sphericity and the scattering phase of individual atmospheric particles. We examine the relationship between a particle's sphericity and its phase function. In addition, we explore the differences in phase function between nonspherical particles that have high sphericity (i.e. complex particles with overall round shape) and spherical particles. We conclude by commenting on the possible impacts of our findings on inversion procedures used in aerosol characterization.

**8:12AM T16.00002 Measurement of aerosol optical properties by integrating cavity ring-down spectroscopy and nephelometery**[1] , GETACHEW TEDELA, SUJEETA SINGH, MARC FIDDLER, SOLOMON BILILIGN, North Carolina A&T State University — Accurate measurement of optical properties of aerosols is crucial for quantifying the influence of aerosols on climate. Aerosols that scatter and absorb radiation can have a cooling or warming effect depending on the magnitude of the respective scattering and absorption terms. One example is black carbon known for its strong absorption. The reported refractive indices for black carbon particles range from 1.2+0i to 2.75+1.44i. Our work attempts to measure extinction coefficient, and scattering coefficient of black carbon particles at different incident beam wavelengths using a cavity ring-down spectrometer and a Nephelometer and compare to Mie theory predictions. We report calibration results using polystyrene latex spheres and preliminary results on using commercial black carbon particles.

[1]The work is supported by the Department of Defense grant W911NF-11-1-0188.

**8:24AM T16.00003 Non-Condensable Gas Absorption by Capillary Waves** , MATTHIEU A. ANDRE, PHILIPPE M. BARDET, The George Washington University — Oceans and atmosphere are constantly exchanging heat and mass; this has a direct consequence on the climate. While these exchanges are inherently multi-scales, in non-breaking waves the smallest scales strongly govern the transfer rates at the ocean-atmosphere interface. The present experimental study aims at characterizing and quantifying the exchanges of non-condensable gas at a sub-millimeter scale, in the presence of capillary waves. In oceans, capillaries are generated by high winds and are also present on the forward face of short gravity waves. Capillary waves are thus present over a large fraction of the ocean surface, but their effect on interphase phenomena is little known. In the experiment, 2D capillary waves are generated by the relaxation of a shear layer at the surface of a laminar water slab jet. Wave profile is measured with Planar Laser Induced Fluorescence (PLIF) and 2D velocity field of the water below the surface is resolved with Particle Image Velocimetry (PIV). Special optical arrangements coupled with high speed imaging allow 0.1 mm- and 0.1 ms- resolution. These data reveal the interaction of vorticity and free surface in the formation and evolution of capillaries. The effect of the capillaries on the transfer of oxygen from the ambient air to anoxic water is measured with another PLIF system. In this diagnostic, dissolved oxygen concentration field is indirectly measured using fluorescence quenching of Pyrenebutyric Acid (PBA). The three measurements performed simultaneously -surface profile, velocity field, and oxygen concentration- give deep physical insights into oxygen transfer mechanisms under capillary waves.

**8:36AM T16.00004 The relation between the statistics of open ocean currents and the temporal correlations of the wind-stress** , GOLAN BEL, YOSEF ASHKENAZY, Ben-Gurion University of the Negev — We study the statistics of wind-driven open ocean currents. Using the Ekman layer model for the integrated currents, we investigate, analytically and numerically, the relation between the wind-stress distribution and its temporal correlations and the statistics of the open ocean currents. We find that temporally long-range correlated wind results in currents whose statistics is proportional to the wind-stress statistics. On the other hand, short-range correlated wind leads to Gaussian distributions of the current components, regardless of the stationary distribution of the winds, and therefore, to a Rayleigh distribution of the current amplitude, if the wind-stress is isotropic. We find that the second moment of the current speed exhibits a maximum as a function of the correlation time of the wind-stress for a non-zero Coriolis parameter. The results were validated using an oceanic general circulation model.

**8:48AM T16.00005 Stochastic Parameterization of Ocean Mesoscale Eddies** , LAURE ZANNA, LUCA MANA, University of Oxford — Processes smaller than the model resolution or faster than the model time step are parameterized in climate simulations using deterministic closure schemes. Yet, several subgrid-scale processes are turbulent and potentially best represented by stochastic closures. The goal of our study is to construct a stochastic parameterization of mesoscale eddies in ocean models. The output of a quasi-geostrophic model in a double-gyre configuration with horizontal resolution of 7.5 km (eddy-resolving resolution) is used as the "truth". A coarse-graining methodology is employed on this output to compute "eddy fluxes" tendencies appropriate to the grid scale of a coarse resolution model. The tendencies are binned into different ranges of mean flow and mean shear strength related to the eddy life cycle in order to obtain probability distribution functions (PDFs). The PDFs for the coarse-grained tendencies show that the temporal and spatial eddy fluxes cannot be captured by current downgradient deterministic parameterizations. We rely on the PDFs to implement a novel stochastic parameterization into a coarse resolution model. We show and discuss the impact of this new parameterization on the mean flow and its fluctuations.

**9:00AM T16.00006 Nonlinear Scale Interactions and Energy Pathways in the Ocean** , HUSSEIN ALUIE, MATTHEW HECHT, LANL, GEOFFREY VALLIS, KIRK BRYAN, Princeton/GFDL, MATHEW MALTRUD, ROBERT ECKE, BETH WINGATE, LANL — Large-scale currents and eddies pervade the ocean and play a prime role in the general circulation and climate. The coupling between scales ranging from $O(10^4)$ km down to $O(1)$ mm presents a major difficulty in understanding, modeling, and predicting oceanic circulation and mixing, where the energy budget is uncertain within a factor possibly as large as ten. Identifying the energy sources and sinks at various scales can reduce such uncertainty and yield insight into new parameterizations. To this end, we refine a novel coarse-graining framework to directly analyze the coupling between scales. The approach is very general, allows for probing the dynamics simultaneously in scale and in space, and is not restricted by usual assumptions of homogeneity or isotropy. We apply these tools to study the energy pathways from high-resolution ocean simulations using LANL's Parallel Ocean Program. We examine the extent to which the traditional paradigm for such pathways is valid at various locations such as in western boundary currents, near the equator, and in the deep ocean. We investigate the contribution of various nonlinear mechanisms to the transfer of energy across scales such as baroclinic and barotropic instabilities, barotropization, and Rossby wave generation.

**9:12AM T16.00007 Suppressing Rayleigh-Taylor Instability with rotation**[1] , MATTHEW SCASE, RICHARD HILL, KYLE BALDWIN, University of Nottingham — The stabilizing effects of rotation upon many instabilities are well known. We demonstrate how the Rayleigh-Taylor instability (RTI) in a two-layer fluid may be stabilized by rotating the fluid, and present a critical rotation rate for such stabilization. We show that, in contrast to non-rotating RTI, there is a fundamental difference between placing heavy fluid above a light fluid (unstable arrangement) and simply accelerating a stable arrangement (light above heavy) at a rate greater than gravity vertically downwards. We propose to show novel experiments, conducted using high-powered superconducting magnets (18.7 T), supporting the theoretical predictions. We believe these to be the first experiments to investigate the effects of rotation upon RTI and they exploit the use of the magnetic field that removes the need for a physical barrier when initializing the experiment. Potential applications for the research lie not only in fundamental fluid mechanics, but also in astrophysical applications where RTI is observed (e.g. Crab Nebula) and other strategic applications.

[1]Supported under EPSRC Grant EP/K50354X/1.

**9:24AM T16.00008 Inverse Energy cascade in 3D Navier-Stokes eqs** , LUCA BIFERALE, University of Rome "Tor Vergata", Italy, STEFANO MUSACCHIO, CNRS-Nice, France, FEDERICO TOSCHI, Applieed Physics, TUE, The Netherlands, ICTR COLLABORATION — We study the statistical properties of homogeneous and isotropic three-dimensional (3D) turbulent flows. We show that all 3D flows in nature possess a subset of possible non-linear evolution leading to a reverse energy transfer: from small to large scales. Up to now, such inverse cascade was only observed in flows under strong rotation and in quasi two-dimensional geometries under strong confinement. We show here that energy flux is always reversed when mirror symmetry is broken leading to a distribution of helicity in the system with a well defined sign at all wavenumbers. Our findings broaden the range of flows where inverse energy cascade may be detected and rationalize the role played by helicity in the energy transfer process showing that both 2D and 3D properties naturally coexist in all flows in nature.

**9:36AM T16.00009 Rotation rate of tracer and long rods in turbulence** , SHIMA PARSA, GREG VOTH, Wesleyan University — We study the rotational dynamics of single rod-like particles ranging from tracer rods to long rods and quantify the effects of length of rod on its rotation rate in turbulent flow. The orientation and position of rods are measured experimentally using Lagrangian particle tracking with images from multiple cameras in a flow between two oscillating grids. Rods rotate due to the velocity gradient of the flow and also develop alignment with the directions of the velocity gradient tensor as they are carried by the flow. Small tracer rods rotate due to the velocity gradient of the smallest eddies that produce the largest shear rate while longer rods average over length-scales smaller than their size to eddies order of their own length-scales. The rotation rate variance gets smaller as the length of the rod increases.

**9:48AM T16.00010 ABSTRACT WITHDRAWN** —

**10:00AM T16.00011 Intermittency in 2D Turbulence** , WALTER GOLDBURG, RORY CERBUS, Department of Physics and Astronomy, University of Pittsburgh — The existence of intermittency in three-dimensional turbulence is generally accepted, although with a variety of interpretations. However, the issue of intermittency in two- dimensional turbulence is unresolved. By measuring the velocity in a flowing soap film, we show that there is significant intermittency in both the enstrophy and energy cascades. The intermittency is characterized by the scaling exponents of velocity structure functions $S_n(r)$ as well as the flatness $F$ of velocity derivatives. Both show a strong Reynolds number dependence. However, unlike turbulence in three dimensions, the intermittency decreases with increasing Reynolds number. This work is supported by NSF grant No. 1044105, a Mellon fellowship, and the Okinawa Institute of Science and Technology.

**10:12AM T16.00012 From a Desingularized Vortex Sheet Model to a Turbulent Mixing Layer** , UJJAYAN PAUL, RODDAM NARASIMHA, Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR) — The temporal mixing layer is studied using the model of a slightly perturbed vortex sheet which is unstable and tends to roll-up in a spiral. The flow is inviscid and incompressible. A point vortex model tends to evolve into a chaotic cloud of point vortices instead of a smooth double branched spiral. The vortex sheet model is derived (in closed form) from the basic equations of vortex dynamics. The problem of finite time singularity is handled by a technique that invokes longitudinal circulation density diffusion along the sheet at singular points. The present model uses linear segments to interpolate the sheet. Although it is computationally involved compared to point vortices, the vortex sheet does not get distorted and rolls-up into a smooth double branched spiral. The accuracy of such simulations can be independently verified by using the laws of vortex dynamics and conserved quantities. We observe the growth of the two-dimensional shear layer with time and the merger of vortex like structures. The dependence of the mixing layer on the initial conditions is studied in detail and tries to answer the question whether the vortex sheet model yields a turbulent mixing layer.

**10:24AM T16.00013 Return to isotropy in high Reynolds number turbulent shear flow** , CHERYL KLIPP, US Army Research Laboratory — Given that turbulence decays from large scales to smaller scales, and that large scales are anisotropic and the smallest scales are isotropic, can the results of return to isotropy experiments be applied to the cascade of turbulence from large scales to small scales? If energy is added to the system only at larger scales, then probably yes. For atmospheric flow over relatively open and flat terrain (Kansas), the 'decay' of turbulence progresses from fairly anisotropic at the large scales (maximum turbulent kinetic energy) toward pure isotropy at smaller scales via pancake-like axisymmetry. The smallest scale resolvable by the instrumentation is on the order of 1m, so dissipation scales are not evaluated. The flows with cigar-like axisymmetry occur inside an urban canyon. In these cases it is not clear if turbulence is generated at only the maximum turbulent kinetic energy scale. The turbulence at larger scales possesses a strong cigar-like axisymmetry, but can often progress to pancake-like axisymmetry at smaller scales.

**10:36AM T16.00014 Information Content of Turbulence** , RORY CERBUS, WALTER GOLDBURG, Department of Physics and Astronomy, University of Pittsburgh — This work is one of the few attempts to treat turbulence as an information source that can be controlled experimentally. As the Reynolds number $Re$ is increased, more degrees of freedom are excited and participate in the turbulent cascade. One might therefore expect that on raising $Re$, the system becomes more random, thereby increasing the Shannon entropy $H$. However, because the excited modes are correlated, $H$ is a *decreasing* function of $Re$, as is experimentally shown in a study of turbulence in a flowing soap film. A parallel analysis was made of the logistic map, where $H$ is calculated as a function of the control parameter $r$ in the equation $x_{n+1} = rx_n(1 - x_n)$. There, as expected, $H$ is an increasing function of $r$. This work is supported by NSF grant No. 1044105, a Mellon fellowship, and the Okinawa Institute of Science and Technology.

**10:48AM T16.00015 A hypothesis on nanodust as a source of energy for extreme weather events and climate changes** , SIMON BERKOVICH, The George Washington University — There are many phenomena that attract energy, the source of which cannot be unerringly identified. Among those are: excess heat alleged to nuclear processes, sonoluminescence, wire fragmentation under high voltage pulses, diverse biophysical experiences, and some atmospheric effects, like ball lightning and terrestrial gamma rays. Destructive atmospheric events associated with intense air movements, such as hurricanes and tornadoes, expend huge amounts of energy equivalent to very many nuclear bombs. Our paper [1] indicates a possibility for a new source of energy due to the so-called "hot-clocking" effect related to the holographic mechanism of the Universe that establishes the exclusive property of nonlocality. This may uncover energy in various unusual appearances, particularly, in the suspected trend of global warming as a direct contribution to the extreme weather events. The surmised clocking impacts from holographic reference beam can reveal themselves through gaseous aerosols and suspended contaminants that may have been increased with human technogenesis. According to recent EPRI report nanopowder for Ni-Pd alloys in the size range of 5–10 nm was found to cause small amounts of excess power, about 4 watt per gram. So, using a minimal norm of contamination (20 micrograms per cubic meter) as an approximate guide, we could estimate that the whole atmosphere would thus generate dozens of terawatts, a contribution comparable to that of the Sun. [1] S.Berkovich, "Generation of clean energy by applying parametric resonance to quantum nonlocality clocking", **Nanotech,** 2011 Vol. 1, pp.771-774

# Thursday, March 21, 2013 2:30PM - 5:30PM –

Session W32 DPOLY DFD: Focus Session: Micro/Nanofluidics I 340 - Daeyeon Lee, University of Pennsylvania

**2:30PM W32.00001 Uncovering stem-cell heterogeneity in the microniche with label-free microfluidics**[1] , LYDIA L. SOHN, University of California, Berkeley — Better suited for large number of cells from bulk tissue, traditional cell-screening techniques, such as fluorescence-activated cell sorting (FACS) and magnetic-activated cell sorting (MACS), cannot easily screen stem or progenitor cells from minute populations found in their physiological niches. Furthermore, they rely upon irreversible antibody binding, potentially altering cell properties, including gene expression and regenerative capacity. We have developed a label-free, single-cell analysis microfluidic platform capable of quantifying cell-surface marker expression of functional organ stem cells directly isolated from their micro-anatomical niche. With this platform, we have screened single quiescent muscle stem (satellite) cells derived from single myofibers, and we have uncovered an important heterogeneity in the surface-marker expression of these cells. By sorting the screened cells with our microfluidic device, we have determined what this heterogeneity means in terms of muscle stem-cell functionality. For instance, we show that the levels of beta1-integrin can predict the differentiation capacity of quiescent satellite cells, and in contrast to recent literature, that some CXCR4+ cells are not myogenic. Our results provide the first direct demonstration of a microniche-specific variation in gene expression in stem cells of the same lineage. Overall, our label-free, single-cell analysis and cell-sorting platform could be extended to other systems involving rare-cell subsets.

[1] This work was funded by the W. M. Keck Foundation, NIH, and California Institute of Regenerative Medicine

**3:06PM W32.00002 Designing artificial phagocyte that selectively "ingests" solutes** , ALEXANDER ALEXEEV, KATHERINE C. POLHEMUS, AYUKO MORIKAWA, Georgia Institute of Technology — We use dissipative particle dynamics to design an active composite vesicle that can controllably and selectively "ingest" solutes from the surrounding fluid. The vesicle consists of a lipid membrane that envelops a stimuli-responsive microgel particle. When the microgel swells and increases in size due to an external stimulus, the lipid membrane breaks forming pores that expose a part of the microgel to the external solvent. Solutes initially dispersed in the solvent diffuse and bind to the uncovered surface of microgel particles. After the stimulus is removed and microgel deswells to its original size, the transmembrane pores close isolating the adsorbed solutes inside the vesicle. In our simulations, we formulate the criteria for the controlled pore opening and closing, and probe how this smart vesicle can be harnessed to "ingest" specific macromolecules. Our results will be useful for developing a new class of artificial phagocytes for targeted sampling in various biomedical applications.

**3:18PM W32.00003 Transient Flow Induced by the Adsorption of Particles**[1] , NAGA MUSUNURI, DANIEL CODJOE, BHAVIN DALAL, IAN FISCHER, PUSHPENDRA SINGH, New Jersey Institute of Technology — When small particles, e.g., glass, flour, pollen, etc., come in contact with a fluid-liquid interface they disperse so quickly to form a monolayer on the interface that it appears explosive, especially on the surface of mobile liquids like water. This is a consequence of the fact that the adsorption of a particle in an interface causes a lateral flow which on the interface away from the particle. In this study we use the particle image velocimetry (PIV) technique to measure the transient three-dimensional flow that arises due to the adsorption of spherical particles. The PIV measurements show that the flow develops a fraction of a second after the adsorption of the particle and persists for several seconds. The fluid below the particle rises upwards and on the surface moves away from the particle. These latter PIV results are consistent with the surface velocity measurements performed in earlier studies. The strength of the induced flow, and the time duration for which the flow persists, both decrease with decreasing particle size. For a spherical particle the flow is axisymmetric about the vertical line passing through the center of the particle.

[1] National Science Foundation

**3:30PM W32.00004 ABSTRACT WITHDRAWN –**

**3:42PM W32.00005 Direct measurement of friction of a fluctuating contact line** , SHUO GUO, Department of Physics, Hong Kong University of Science and Technology, MIN GAO, Department of Mathematics, Hong Kong University of Science and Technology, XIAOMIN XIONG, Department of Physics, Sun Yat-sen University, YONG JIAN WANG, Department of Physics, Hong Kong University of Science and Technology, XIAOPING WANG, Department of Mathematics, Hong Kong University of Science and Technology, PING SHENG, PENGER TONG, Department of Physics, Hong Kong University of Science and Technology* — What happens at a moving contact line, where one fluid displaces another (immiscible) fluid over a solid surface, is a fundamental issue in fluid dynamics. In this presentation, we report a direct measurement of the friction coefficient in the immediate vicinity of a fluctuating contact line using a micron-sized vertical glass fiber with one end glued to an atomic force microscope (AFM) cantilever beam and the other end touching a liquid-air interface. By measuring the broadening of the resonance peak of the cantilever system with varying liquid viscosity $\eta$, we obtain the friction coefficient $\xi_c$ associated with the contact line fluctuations on the glass fiber of diameter $d$ and find it has the universal form, $\xi_c = 0.8\pi d\eta$, independent of the contact angle. The result is further confirmed by using a soap film system whose bulk effect is negligibly small. This is the first time that the friction coefficient of a fluctuating contact line is measured. *Work supported by the Research Grants Council of Hong Kong SAR.

**3:54PM W32.00006 Giant slip at liquid-liquid interfaces using a hydrophobic ball bearing** , LAURENT JOLY, QUENTIN EHLINGER, OLIVIER PIERRE-LOUIS, LPMCN - Université Lyon 1, France — We suggest to build an interface where hydrophobic beads maintain a gas layer between two liquids. We show that this interface behaves as a liquid-liquid ball bearing under shear and exhibits giant slip. Such a metastable configuration reminds of pillar-based superhydrophobic surfaces, used to amplify liquid-solid slip. To the advantage of hydrophobic ball bearings, beads are able to roll, thereby reducing friction at the liquid-bead interface. However beads will always penetrate inside the liquid, inducing viscous dissipation and consequently decreasing slippage. The penetration depth being directly controlled by the wetting angle of the liquid at the bead surface, the latter is expected to have a strong influence on the efficiency of the liquid/liquid bearing. We start by quantifying analytically the influence of the wetting angle on liquid/liquid slip in this system. We then confirm the obtained scaling law by means of Molecular Dynamics (MD) simulations. Liquid-liquid bearings open new pathways for micro and nanofluidics. One major direction could be to build fluidic channels without walls, where different liquids in contact could flow independently while maintaining an extremely low interfacial friction, and preventing mixing by diffusion between the different channels.

**4:06PM W32.00007 A Study of the Concentration Dependent Water Diffusivity in Polymer using Magnetic Resonance Imaging** , HOWON LEE, Massachusetts Institute of Technology, JIAXI LU, JOHN GEORGIADIS, University of Illinois at Urbana-Champaign, NICHOLAS FANG, Massachusetts Institute of Technology — Hydrogel allows solvent molecules to migrate in and out of the polymer network, often in response to various environmental stimuli such as temperature and pH, resulting in significant volumetric change. Kinetics of penetrants in polymeric network determines time dependent behavior of hydrogel. However, swelling deformation resulting from the solvent uptake in turn significantly changes diffusivity of solvent, and this strong coupling makes it challenging to study dynamic behavior of hydrogels. Here we study concentration dependent diffusivity of water in poly(ethylene glycol) diacrylate (PEGDA) hydrogel using magnetic resonance imaging (MRI). Projection micro-stereolithography is used to fabricate gel samples in which a gradient of water volume fraction occurs. In situ measurement using MRI provides quantitative relationship between diffusivity and volume fraction of water in the gel. This result will help better understand interstitial diffusion behavior of solvent in polymers, which has great implication in board areas such as soft matter mechanics, drug delivery, and tissue engineering.

**4:18PM W32.00008 Closing the loop in the boundary layer: water slippage, interfacial viscosity and wettability**[1] , ELISA RIEDO, School of Physics, Georgia Institute of Technology, DEBORAH ORTIZ-YOUNG, School of Chemistry, Georgia Institute of Technology, HSIANG-CHIH CHIU, School of Physics, Georgia Institute of Technology, KISLON VOÏTCHOVSKY, Institute of Materials, Ecole Polytechnique Fédérale de Lausanne, SUENNE KIM, School of Physics, Georgia Institute of Technology — Understanding and manipulating fluids at the nanoscale is a matter of growing scientific and technological interest. Here, we present experiments showing that the interfacial viscosity of water depends drastically on the wetting properties of the confining surfaces. By using an atomic force microscope (AFM), we have measured the lateral viscous force experienced in water by a nano-size AFM tip while it is sheared in parallel to a smooth solid surface, as a function of the tip-surface distance. The viscous force curves, FL(d), have been measured for five surfaces with various wettabilities. In particular, the experiments indicate that in water lower forces are required to shear a tip very close to a slippery non-wetting surface, yielding to a lower effective viscosity. A modified form of the Newtonian definition of viscosity, which includes slippage, is used to successfully predict the measured shear forces in the boundary layer as a function of surface wettability, and slippage. We prove that this effect is general and can be applied in different contexts such as in explaining the relationship between dissipation and surface wettability for a nano-tip vibrating in proximity of a surface in water.

[1]DOE (DE-FG02-06ER46293)/NSF (DMR-0120967 and DMR-0706031)

**4:30PM W32.00009 Molecular Dynamic Studies of Thermal Resistance and Temperature Jumps in Confined Nanofilms** , P. THOMPSON, California Instiute of Technology, MC 128-95, Pasadena, CA 91125, . ., . — In macroscale systems, it is always assumed that two adjoining materials adopt equal temperatures across the surface of contact. In fact, even in the presence of a thermal flux, the contacting boundary is believed to remain in thermal equilibrium so long as the interfacial resistance is small in comparison to that of the bulk. This has long been assumed an especially good approximation for liquid/solid (L/S) interfaces since liquids easily conform in shape to an adjacent substrate. Recent MD simulations of liquid nanofilms subject to a constant thermal gradient, however, have revealed the existence of large intrinsic temperature jumps. The magnitude of these jumps is traceable to proximity effects including the depth of the attraction potential between the liquid and solid and the degree of fluid layering near the interface. As expected, increased commensurability between the adjoining phases leads to a decrease in thermal resistance. Here we discuss how non-local effects caused by the magnitude of the overall thermal flux can lead to linear enhancement in the temperature jump. This finding suggests that temperature jumps across a liquid/solid interface depend not only on density mismatch effects but the actual rate of heat transfer in confined nanoscale films.

**4:42PM W32.00010 Near-wall Brownian motion of anisotropic particles** , SADAO OTA, TONGCANG LI, YIMIN LI, ZILIANG YE, ANNA LABNO, XIAOBO YIN, M-REZA ALAM, XIANG ZHANG, UC Berkeley — Anisotropic microscopic objects are ubiquitous such as biological cells, filamentous macromolecules, as well as synthesized nanomaterial. Near interfaces, the thermal motion of these objects is strongly constrained due to the hydrodynamic interactions, impacting the overall behavior of the biophysical and colloidal systems. Thus, understanding this wall-effect is a key to describe many surface-related problems. Unlike the well-studied case of spheres, however, both its experimental and theoretical studies have been elusive due to the intrinsic complexity of the system. Here we present a comprehensive experimental and computational study of the Brownian motion of silicon nanowires tethered on a substrate. A uniquely developed interference method enables the direct visualization of its microscopic rotations in three dimensions with high angular and temporal resolutions. The quantitative measurement at short time scales revealed the anisotropic reduction in their rotational diffusivities as a function of the inclined angles, resulting in the decrease more than 40-80 % at long time scales. We then developed a numerical model from a string-of-beads idealization, which implicitly simulates the complex hydrodynamic interaction and showed excellent agreement with the experimental observations. Our study provides insights into the fundamental diffusive processes, useful for understanding the anisotropic behavior of anisotropic macromolecules near interfaces. The demonstrated methods offers a systematic approach for studying the interfacial rheology of various anisotropic objects.

**4:54PM W32.00011 Enhancing microscale particle deposition using actuated synthetic cilia** , MATTHEW S. BALLARD, ZACHARY G. MILLS, ALEXANDER ALEXEEV, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, Georgia 30032 — We use three dimensional simulations to examine deposition of diffusive nanoscopic particles suspended in a viscous fluid onto the walls of a microchannel containing an array of actuated synthetic cilia. We model the cilia as elastic filaments attached to the channel walls and actuated by an external periodic force. We use a lattice Boltzmann model coupled with a lattice spring model to simulate the system and investigate the effects of the oscillating cilia on the rate of particle deposition. We consider the effects of variation of cilia properties and spacing, as well as the frequency and amplitude of the applied force on the deposition of particles with different diffusivity. Our findings are useful in understanding how active microscopic structures can be harnessed to design microfluidic devices and surfaces with controllable transport properties.

### 5:06PM W32.00012 Statics and dynamics of polymer droplets on topographically structured substrates[1]

, MARCUS MUELLER, NIKITA TRETYAKOV, Georg-August University, Gottingen, Germany — Using Molecular Dynamics simulations of a polymer liquid flowing past flat and patterned surfaces, we investigate the influence of corrugation, wettability and pressure on slippage and friction at the solid-liquid interface. We devise a computational method to compute the interface potential that does not rely on grandcanonical simulation techniques and quantitatively compare droplet profiles obtained in simulations with the predictions of a thin-film equation using the independently determined interface potential. For substrates structured by one-dimensional, rectangular grooves, we observe a gradual crossover between the Wenzel state, where the liquid fills the grooves, and the Cassie state, where the corrugation supports the liquid and the grooves are filled with vapor. Using two independent flow set-ups, we characterize the near-surface flow by the slip length and the position, at which viscous and frictional stresses are balanced according to Navier's partial slip boundary condition. This hydrodynamic boundary position depends on the pressure inside the channel and may be located above the corrugated surface. In the Cassie state, we observe that the edges of the corrugation contribute to the friction.

[1]This work was supported by the European Union under grant PITN-GA-2008-214919 (MULTIFLOW).

### 5:18PM W32.00013 The Effect of Polarization on Structure, Dynamics and Electric Double Layer for Interfacial Water near Charged Graphene[1]

, ALBERTO STRIOLO, TUAN A. HO, The University of Oklahoma, MOLECULAR SCIENCE AND ENGINEERING TEAM TEAM — A solid surface perturbs water for up to 10-20 Å. Quantifying the structural and dynamics properties of water within this interfacial layer remains crucial for a number of applications, including lab-on-chip and micro- and nano-fluidic devices, and also for designing efficient electric double layers capacitor. As graphene is finding wide applications in the energy sector (batteries and capacitors) we revisited the graphene-water interface. Because at the air-water interface it is known that accounting for the polarization of water and ions is required to properly describe the ions distribution, we conducted a parametric study in which we varied the polarization of carbon atoms on charged graphene. The polarization is described implementing a classic Drude oscillator, which is consistent with the model implemented to describe water and ions. External electric fields are represented by uniform charge distributions on the carbon atoms. The results are quantified in terms of structure and dynamics of interfacial water, as well as of structure of the electric double layer. Comparison with accurate experimental observations is provided.

[1]Acknowledgments: DoE

# Thursday, March 21, 2013 2:30PM - 5:30PM –
## Session W39 DFD: Computational Fluid Dynamics 348 - Gorges L. Chahine, Dynaflo, Inc

### 2:30PM W39.00001 Transient Non-Newtonian Screw Flow

, NARIMAN ASHRAFI, Azad University — The influence of axial flow on the transient response of the pseudoplastic rotating flow is carried out. The fluid is assumed to follow the Carreau-Bird model and mixed boundary conditions are imposed. The four-dimensional low-order dynamical system, resulted from Galerkin projection of the conservation of mass and momentum equations, includes additional nonlinear terms in the velocity components originated from the shear-dependent viscosity. In absence of axial flow the base flow loses its radial flow stability to the vortex structure at a lower critical Taylor number, as the pseudoplasticity increases. The emergence of the vortices corresponds to the onset of a supercritical bifurcation which is also seen in the flow of a linear fluid. However, unlike the Newtonian case, pseudoplastic Taylor vortices lose their stability as the Taylor number reaches a second critical number corresponding to the onset of a Hopf bifurcation. Existence of an axial flow, manifested by a pressure gradient appears to further advance each critical point on the bifurcation diagram. In addition to the simulation of spiral flow, the proposed formulation allows the axial flow to be independent of the main rotating flow. Complete transient flow field together with viscosity maps are also presented.

### 2:42PM W39.00002 Indeterminism in Classical Dynamics of Particle Motion

, GREGORY EYINK, The Johns Hopkins University, ETHAN VISHNIAC, University of Saskatchewan, CRISTIAN LALESCU, The Johns Hopkins University, HUSSEIN ALUIE, Los Alamos National Laboratory, KALIN KANOV, RANDAL BURNS, CHARLES MENEVEAU, ALEX SZALAY, The Johns Hopkins University — We show that "God plays dice" not only in quantum mechanics but also in the classical dynamics of particles advected by turbulent fluids. With a fixed deterministic flow velocity and an exactly known initial position, the particle motion is nevertheless completely unpredictable! In analogy with spontaneous magnetization in ferromagnets which persists as external field is taken to zero, the particle trajectories in turbulent flow remain random as external noise vanishes. The necessary ingredient is a rough advecting field with a power-law energy spectrum extending to smaller scales as noise is taken to zero. The physical mechanism of "spontaneous stochasticity" is the explosive dispersion of particle pairs proposed by L. F. Richardson in 1926, so the phenomenon should be observable in laboratory and natural turbulent flows. We present here the first empirical corroboration of these effects in high Reynolds-number numerical simulations of hydrodynamic and magnetohydrodynamic fluid turbulence. Since power-law spectra are seen in many other systems in condensed matter, geophysics and astrophysics, the phenomenon should occur rather widely. Fast reconnection in solar flares and other astrophysical systems can be explained by spontaneous stochasticity of magnetic field-line motion

### 2:54PM W39.00003 Higher Order Thermal Lattice Boltzmann Model[1]

, SHAHAJHAN SORATHIYA[2], SANTOSH ANSUMALI[3], JNCASR — Lattice Boltzmann method (LBM) modelling of thermal flows, compressible and micro flows requires an accurate velocity space discretization. The sub optimality of Gauss-Hermite quadrature in this regard is well known [1]. Most of the thermal LBM in the past have suffered from instability due to lack of proper H-theorem and accuracy [2]. Motivated from these issues, the present work develops along the two works [3] and [4] and imposes an eighth higher order moment to get correct thermal physics. We show that this can be done by adding just 6 more velocities to D3Q27 model and obtain a "multi-speed on lattice thermal LBM" with 33 velocities in 3D and $\mathcal{O}(u^4)$ and $\mathcal{O}(T^4)$ accurate $f_i^{\mathrm{eq}}$ with a consistent H-theorem and inherent numerical stability. Simulations for Rayleigh-Bernard as well as velocity and temperature slip in micro flows matches with analytical results. Lid driven cavity set up for grid convergence is studied. Finally, a novel data structure is developed for HPC.

[1] X. Shan and X. He, Phys. Rev. Lett. 80, 65 (1998).
[2] G. McNamara, A. Garcia, and B. Alder, J. Stat. Phys. 81, 395 (1995).
[3] S. Chikatamarla and I. Karlin, Phys. Rev. E 79, 046701 (2009).
[4] W. Yudistiawan et al. Phys. Rev. E 82, 046701 (2010)

[1]The authors express their gratitude for computational resources and financial support provide by Jawaharlal Nehru Centre for Advanced Scientific Research (JNCASR), Bangalore, India.
[2]Graduate Student, Engineering Mechanics Unit, JNCASR, India.
[3]Faculty Fellow, Engineering Mechanics Unit, JNCASR, India.

**3:06PM W39.00004 ODTLES: Simulations of wall-bounded turbulent flows with small-scale resolution**[1] , ESTEBAN GONZALEZ, Combustion Science & Engineering, Inc., ALAN KERSTEIN, Consultant, ROD SCHMIDT, Sandia National Laboratories — The numerical simulation of turbulent flows is difficult because of their broad range of scales of motion and because they include a large variety of small-scale processes, such as friction near a wall, diffusion at an interface, multiphase couplings, and chemical reactions. Traditional approaches to model these flows are limited in breadth and accuracy because they filter out information from small-scale processes. An alternative method that circumvents this problem is ODTLES. This method resolves, not models, small-scale phenomena in a computationally affordable way, in comparison with full three-dimensional resolution, through the use of a lattice-work of one-dimensional (1D) domains, where flow properties are time-advanced with 1D stochastic simulations. This talk will discuss the methodology behind ODTLES and results for incompressible wall-bounded turbulence.

[1]This work is supported by the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, Geosciences, and Biosciences.

**3:18PM W39.00005 Shock Formation and Disintegration in Fluids with Non-Convex Equations of State**[1] , FATEMEH BAHMANI, MARK CRAMER, Virginia Polytechnic Institute and State University — We consider the steady, two-dimensional, inviscid, high-speed, flow around thin turbine blade profiles with special attention given to fluids having a non-convex equation of state; such fluids are commonly known as Bethe-Zel'dovich-Thompson (BZT) fluids. We show that the essential flow physics can be described by an inviscid Burgers equation having quartic nonlinearity rather than the quadratic nonlinearity of perfect gases. In order to illustrate the flow behavior, a fifth-order WENO (weighted essentially non-oscillatory) numerical scheme is employed. New results of interest include the formation of oblique expansion shocks, shock-splitting induced by the interaction of a single shock with Mach waves, the capture of shock-fan combinations, and the collision of oblique compression and expansion shocks.

[1]NSF grant CBET-0625015

**3:30PM W39.00006 Polarized Turbulence on the 3-sphere** , OWEN DIX, RENA ZIEVE, University of California, Davis — We have simulated He II superfluid turbulence on a 3-sphere, using the Hopf vector field $(-y, x, -w, z)$ as the driving velocity. This vector field lies along parallel great circles of the 3-sphere. It has a uniform magnitude, is divergence-free, and is analogous to a uniform driving velocity in periodic boundaries (a flat 3-torus), with the important exception that it has a non-zero curl tangent to the field itself. The resultant system is an interesting modification of rotating counterflow turbulence, which produces a state of polarized turbulence for driving velocities above a critical velocity $V_{DG}$. The average polarization of the vortex tangent field on the 3-sphere is 0.8-0.95, significantly higher than rotating counterflow. We also found a vortex reconnection rate proportional to $L^{1.6}$, in contrast to homogeneous turbulence, which yields exponents of 5/2 or 2, depending on the importance of the local velocity term and on the turbulence state. A reduced exponent is consistent with predictions and previous simulations of polarized turbulence, but the degree of reduction is remarkable. Development of this polarized turbulence state is still under investigation.

**3:42PM W39.00007 A Spectral Adaptive Mesh Refinement Method for the Burgers equation** , LEILA NASR AZADANI, Graduate Student, ANNE STAPLES, Assistant Professor — Adaptive mesh refinement (AMR) is a powerful technique in computational fluid dynamics (CFD). Many CFD problems have a wide range of scales which vary with time and space. In order to resolve all the scales numerically, high grid resolutions are required. The smaller the scales the higher the resolutions should be. However, small scales are usually formed in a small portion of the domain or in a special period of time. AMR is an efficient method to solve these types of problems, allowing high grid resolutions where and when they are needed and minimizing memory and CPU time. Here we formulate a spectral version of AMR in order to accelerate simulations of a 1D model for isotropic homogenous turbulence, the Burgers equation, as a first test of this method. Using pseudo spectral methods, we applied AMR in Fourier space. The spectral AMR (SAMR) method we present here is applied to the Burgers equation and the results are compared with the results obtained using standard solution methods performed using a fine mesh.

**3:54PM W39.00008 Multiscale simulation of electroosmotic flows** , LIN GUO, MARK ROBBINS, Johns Hopkins University, SHIYI CHEN, Johns Hopkins University, Peking University, JIN LIU, Washington State University — We develop an efficient hybrid multiscale method for simulating nano-scale electroosmotic flow based on spatial "domain decomposition" [1]. Molecular dynamics (MD) is used in the near wall region where atomistic details are important. A multigrid Particle-Particle Particle-Mesh (PPPM) method [2] is used to calculate the long-range Coulombic interaction between charged ions. Continuum (incompressible Navier-Stokes) equations for the solvent are solved in the bulk region, reducing the computational cost substantially. A discrete description of ions is retained in the continuum region because of the low density of ions and the long-range of electrostatic interactions. Langevin dynamics is used to model the Brownian motion of these ions in the implicit solvent. The fully atomistic and continuum descriptions are coupled through "constrained dynamics" [1] in an overlap region. Continuity of flux of both charged and solvent particles is ensured. The scheme is implemented in channel flow simulations with and without wall roughness. Results are compared with pure MD simulations.

[1] X. Nie, S. Chen, W. E, and M. O. Robbins, J. Fluid Mech., 500:55-64, 2004.
[2] J. Liu, M. Wang, S. Chen, and M. O. Robbins, J. Comput. Phys., 229:7834-7847, 2010.

**4:06PM W39.00009 Chaos Synchronization in Navier-Stokes Turbulence**[1] , CRISTIAN LALESCU, CHARLES MENEVEAU, GREGORY EYINK, The Johns Hopkins University — Chaos synchronization (CS) has been studied for some time now (Pecora & Carroll 1990), for systems with only a few degrees of freedom as well as for systems described by partial differential equations (Boccaletti et al 2002). CS in general is said to be present in coupled dynamical systems when a specific property of each system has the same time evolution for all, even though the evolution itself is chaotic. The Navier-Stokes (NS) equations describe the velocity for a wide range of fluids, and their solutions are usually called turbulent if fluctuation amplitudes decrease as a power of their wavenumber. There have been some studies of CS for continuous systems (Kocarev et al 1997), but CS for NS turbulence seems not to have been investigated so far. We focus on the synchronization of the small scales of a turbulent flow for which the time history of large scales is prescribed. Our DNS results show that high-wavenumbers in turbulence are fully slaved to modes with wavenumbers up to a critical fraction of the Kolmogorov dissipation wavenumber. The motivation for our work is to study deeply sub-Kolmogorov scales in fully developed turbulence (Schumacher 2007), which we found to be recoverable even at very high Reynolds number from simulations with moderate resolutions.

[1]This work is supported by the National Science Foundation's CDI-II program, project CMMI-0941530

### 4:18PM W39.00010 Multiscale Modeling of Cavitating Bubbly Flows[1] , J. MA, C.-T. HSIAO, G.L. CHAHINE, Dynaflow, Inc — Modeling of cavitating bubbly flows is challenging due to the wide range of characteristic lengths of the physics at play: from micrometers (e.g., bubble nuclei radius) to meters (e.g., propeller diameter or sheet cavity length). To address this, we present here a multiscale approach which integrates a Discrete Bubble Model for dispersed microbubbles and a level set N-S solver for macro cavities, along with a mesoscale transition model to bridge the two. This approach was implemented in 3DYNAFS© and used to simulate sheet-to-cloud cavitation over a hydrofoil. The hybrid model captures well the full cavitation process starting from free field nuclei and nucleation from solid surfaces. In low pressure region of the foil small nuclei are seen to grow large and eventually merge to form a large scale sheet cavity. A reentrant jet forms under the cavity, travels upstream, and breaks it, resulting in a bubble cloud of a large amount of microbubbles as the broken pockets shrink and travel downstream. This is in good agreement with experimental observations based of sheet lengths and frequency of lift force oscillation.

[1]DOE-SBIR, ONR (monitored by Dr. Ki-Han Kim)

### 4:30PM W39.00011 ABSTRACT WITHDRAWN —

### 4:42PM W39.00012 Surface cooling mechanism of fire suppression by aqueous foam , MICHAEL CONROY, RAMAGOPAL ANANTH, U.S. Naval Research Laboratory — We investigate the ability of room-temperature foam to directly cool the surface of a liquid fuel pool at burning conditions and to reduce the fuel vapor pressure. We solve an unsteady, one-dimensional heat conduction equation using the finite element method to predict the temperature within an aqueous foam layer above a liquid fuel (heptane) layer. The sharp gradients in temperature and thermal properties at the foam-fuel interface are treated approximately inside of a thin interfacial layer above the fuel surface. We predict a rapid, significant reduction in the fuel surface temperature due to the large initial temperature gradient and the foam thermal diffusivity. The predicted surface cooling leads to a significant decrease in the fuel vapor pressure in less than a second. The mechanisms of fire suppression by aqueous foams are not well understood and the model predictions show that direct surface cooling could provide an important contribution to fire suppression. Experiments are in progress to quantify the surface cooling effect on heptane pool fire suppression.

### 4:54PM W39.00013 Formation of Kinneyia via shear-induced instabilities in microbial mats , KATHERINE THOMAS, STEPHAN HERMINGHAUS, MPI Dynamics and Self-Organization, HUBERTUS PORADA, Universitat Göttingen, LUCAS GOEHRING, MPI Dynamics and Self-Organization — Kinneyia are a class of microbially mediated sedimentary fossils. Characterised by clearly defined ripple structures, Kinneyia are generally found in areas that were formally littoral habitats and covered by microbial mats. To date there has been no conclusive explanation as to the processes involved in the formation of these fossils. Microbial mats behave like viscoelastic fluids. We propose that the key mechanism involved in the formation of Kinneyia is a Kelvin-Helmholtz instability induced in a viscoelastic film under flowing water. A ripple corrugation is spontaneously induced in the film and grows in amplitude over time. Theoretical predictions show that the ripple instability has a wavelength proportional to the thickness of the film. Experiments carried out using viscoelastic films confirm this prediction. The ripple pattern that forms has a wavelength roughly three times the thickness of the film. This behaviour is independent of the viscosity of the film and the flow conditions. Well-ordered patterns form, with both honeycomb-like and parallel ridges being observed, depending on the flow speed. These patterns correspond well with those found in Kinneyia fossils, with similar morphologies, wavelengths and amplitudes being observed.

### 5:06PM W39.00014 Optimal Concentrations in Transport Networks , KAARE JENSEN, JESSICA SAVAGE, Harvard University, WONJUNG KIM, JOHN BUSH, Massachusetts Institute of Technology, N. MICHELE HOLBROOK, Harvard University — Biological and man-made systems rely on effective transport networks for distribution of material and energy. Mass flow in these networks is determined by the flow rate and the concentration of material. While the most concentrated solution offers the greatest potential for mass flow, impedance grows with concentration and thus makes it the most difficult to transport. The concentration at which mass flow is optimal depends on specific physical and physiological properties of the system. We derive a simple model which is able to predict optimal concentrations observed in blood flows, sugar transport in plants, and nectar feeding animals. Our model predicts that the viscosity at the optimal concentration $\mu_{\rm opt} = 2^n \mu_0$ is an integer power of two times the viscosity of the pure carrier medium $\mu_0$. We show how the observed powers $1 \le n \le 6$ agree well with theory and discuss how $n$ depends on biological constraints imposed on the transport process. The model provides a universal framework for studying flows impeded by concentration and provides hints of how to optimize engineered flow systems, such as congestion in traffic flows.

### 5:18PM W39.00015 Resonating Vector Strength: How to Find Periodicity in a Time Sequence[1] , J. LEO VAN HEMMEN, Physik Department T35, TU Muenchen — For a given periodic stimulus with angular frequency $\omega_\circ = 2\pi/T_\circ$ we find responses as events at times $\{t_1, t_2, \ldots, t_n\}$ located on the real axis $R$. How periodic are they? And do they repeat in "some" sense in accordance with the stimulus period $T_\circ$? The question and the answer are at least as old as a classical paper of von Mises dating back to 1918. The key idea is simply this. We map the events $t_j$ onto the unit circle or torus through $t_j \mapsto \exp(i\omega t_j)$ and consider their center of gravity, $\rho(\omega)$, a complex number in the unit disk. Its absolute value $|\rho(\omega_\circ)|$ with $\omega := \omega_\circ$ is what von Mises studied and is now called the vector strength. We prove that the nearer $|\rho(\omega_\circ)|$ is to $1$ the more periodic the events $t_j$ are w.r.t. $T_\circ$. Furthermore, we also show why it is useful to study $\rho(\omega)$ as a function of $\omega$ so as to obtain a 'resonating' vector strength, an idea strongly deviating from the classical characteristic function.

[1]Work done in collaboration with A.N. Vollmayr. Partially supported by BCCN–Munich.

# Friday, March 22, 2013 8:00AM - 9:36AM —

## Session Y39 DFD: Swimming, Motility and Locomotion 348 - Alexander Alexeev, Georgia Institute of Technology

### 8:00AM Y39.00001 ABSTRACT WITHDRAWN —

### 8:12AM Y39.00002 Navigation and chemotaxis of nematodes in bulk and confined fluids[1] , ALEJANDRO BILBAO, VENKAT PADMANABHAN, Texas Tech University, KENDRA RUMBAUGH, Texas Tech University Health Science Center, SIVA VANAPALLI, JERZY BLAWZDZIEWICZ, Texas Tech University — Small nematodes, such as the model organism *C. elegans*, propel themselves by producing sinuous undulations along the body and perform turns by varying the undulation amplitude. We have recently demonstrated [PLoS ONE 7(7) e40121 (2012)] that such motions can be accurately represented in terms of a piecewise-harmonic body curvature. We combine our harmonic-curvature description with highly accurate hydrodynamic bead-chain models to investigate the swimming efficiency and turning capabilities of the worm in bulk and confined fluids. Our results indicate that for the same change of the curvature-wave amplitude, a swimming nematode turns by a smaller angle compared to a crawling worm. The difference is due to rotational slip with respect to the surrounding medium, but the angles are sufficiently large to allow for efficient turning maneuvers. We use our description of nematode maneuverability to study chemotaxis in both confined and unconfined fluids.

[1]This work was supported by NSF grant No. CBET 1059745.

**8:24AM Y39.00003 Nematode Chemotaxis: Gradual Turns, Sharp Turns, and Modulated Turn Angles**[1] , AMAR PATEL, Texas Tech University, VENKAT PADMANABHAN, Indian Institutes of Technology Kharagpur, KENDRA RUMBAUGH, Texas Tech University Health Sciences Center, SIVA VANAPALLI, JERZY BLAWZDZIEWICZ, Texas Tech University — We examine strategies used by the soil-dwelling nematode *Caenorhabditis Elegans* for chemotaxis in complex environments. The proposed description is based on our recently developed piecewise-harmonic-curvature model of nematode locomotion [PLoS ONE, 7(7) e40121 (2012)], where random harmonic-curvature modes represent elementary locomotory movements. We show that the previously described gradual-turn and sharp-turn chemotaxis strategies can be unified in our model. The gradual-turn mechanism relies on crawling amplitude changes commensurate with the undulation frequency. The sharp-turn mechanism consists in modulation of the frequency of jumps to large-amplitude modes. We hypothesize that there exists a third strategy, where the nematode adjusts the variance of the amplitude distribution. Such adjustments result in a modulation of the magnitude of random turns, with smaller turns performed when the nematode moves toward the increasing chemoatractant concentration. Experiments are proposed to determine if the third strategy is present in the nematode behavior.

[1]This work was supported by NSF grant No. CBET 1059745.

**8:36AM Y39.00004 Simulation of model swimmers near ciliated surfaces** , HENRY SHUM, ANURAG TRIPATHI, Department of Chemical & Petroleum Engineering, University of Pittsburgh, JULIA YEOMANS, Rudolf Peierls Centre for Theoretical Physics, University of Oxford, ANNA BALAZS, Department of Chemical & Petroleum Engineering, University of Pittsburgh — Biofouling by micro-organisms is problematic on scales from microfluidic devices to the largest ships in the ocean. One solution found in nature for clearing undesired material from surfaces is to employ active cilia, for example, in the respiratory tract. It is feasible to fabricate surfaces covered with artificial cilia actuated by an externally imposed field. Using numerical simulation, we investigate the interactions between these artificial cilia and self-propelled model swimmers. One of the key aims is to explore the possibility of steering swimmers to influence their trajectories through the flow field produced by the cilia. In our simulations, the fluid dynamics is solved using the lattice Boltzmann method while the cilia and model swimmers are governed by elastic internal mechanics. We implement an immersed boundary approach to couple the solid and fluid dynamics.

**8:48AM Y39.00005 Underwater propulsion of an internally actuated elastic plate** , PETER YEH, LEJUN CEN, ALPER ERTURK, ALEXANDER ALEXEEV, Georgia Institute of Technology — Combining experiments and numerical simulations we examine underwater locomotion of an active (internally powered) flexible bimorph composite. We use Macro-Fiber Composite (MFC) piezoelectric laminates that are actuated by a sinusoidally varying voltage generating thrust similar to that of a flapping fin in carangiform motion. In our fully-coupled three dimensional simulations, we model this MFC bimorph fin as a thin, elastic plate that is actuated by a time-varying internal moment producing periodic fin bending and oscillations. The steady state swim velocity and thrust are experimentally measured and compared to the theoretical predictions. Our simulations provide detailed information about the flow structures around the swimming fin and show how they affect the forward motion. The results are useful for designing self-propelling fish-like robots driven by internally powered fins.

**9:00AM Y39.00006 Flow generated by an oscillated elastic filament in viscous fluids** , MOUMITA DASGUPTA, ARSHAD KUDROLLI, Clark University — We discuss with experiments the interplay of periodic driving, elasticity, and damping of a cilium in a viscous fluid and the resulting fluid flow. In particular, we oscillate an elastic filament made of PDMS in a viscous Newtonian fluid and observe the generated flow using PIV techniques. The competition between viscous drag and elasticity of the filament is observed to lead to symmetry breaking, resulting in a net flow. The length of the filament is varied to find an optimum length at which maximum net flow is obtained for a given elastic constant of the material and oscillating frequency. We discuss the related coupled oscillator system, and the rich dynamics observed in the context of fluid flow generated by elastic flagella and cilia.

**9:12AM Y39.00007 Transmutation of rotational motion into translational diffusion in 3D rotary powered random walkers** , AMIR NOURHANI, PAUL LAMMERT, Phys. Dept., Penn State, ALI BORHAN, Chem. Eng. Dept., Penn State, VINCENT CRESPI, Phys. Dept., Penn State — Experimenters have for several years been studying motors with sizes in the $10^{-1}$–$10^{0}$ micron range which execute circular motion on scales as small as the motor dimensions in an aqueous environment. Previously, we have studied the normal situation wherein the motor is confined to a plane. Here we consider the case where such confinement is absent. The orbital motion of a particle undergoing regular circular motion in 3D has three rotational degrees of freedom. The introduction of stochasticity into them gives rise to 3D translational motion. A special, and apparently experimentally relevant, case is that of an orbiter in the plane which can flip over, reversing its chirality. We present analytical and simulation results on these transmutations of rotational motion into translational motion

**9:24AM Y39.00008 ABSTRACT WITHDRAWN** —

## Friday, March 22, 2013 8:00AM - 11:00AM –

### Session Y47 DFD GSNP: Invited Session: Controlling and Exploiting Topological Defects in Liquid Crystals Hilton Baltimore Holiday Ballroom 6 - Kathleen Stebe, University of Pennsylvania

**8:00AM Y47.00001 Colloid-in-liquid crystal gels** , NICHOLAS ABBOTT, University of Wisconsin-Madison — This presentation will describe investigations of the collective properties of colloidal particles that are dispersed in liquid crystalline solvents. A focus will be directed to recent observations of the gelation of particles dispersed in thermotropic liquid crystals. While a series of studies over the past decade have revealed two distinct mechanisms leading to gelation of particles in liquid crystalline solvents, our recent observations are inconsistent with both and hint at a third mechanism of gelation. These observations will be described along with examples of how the unique mechanical and optical properties of colloid-in-liquid crystal gels enable the design of biotic-abiotic interfaces.

**8:36AM Y47.00002 TopologicallyRequired Defects in Nematic Liquid Films over Microposts or in contact with Anisotropic Particles** , MOHAMED AMINE GHARBI, Department of Physics and Astronomy. University of Pennsylvania — In this work we present an experimental investigation of topological defects in nematic liquid crystals formed over micropost array with a LC-air interface pinning to the pillar edges or containing washer-shaped microparticles in suspension. For nematic-LC covered microposts with homeotropic anchoring conditions on all boundaries, including the LC-air and LC-substrate interfaces, disclination lines form that bear the signature of the micropost and satisfy global topological constraints of the system. When washer particles with different anchoring conditions are dispersed in homeotropic liquid crystal cells, new topological configurations are observed. In each case, defects are described from both a geometric and topological perspective. Finally, we demonstrate that topological defects created by microposts and washers can generate elastic interactions with dispersed microparticles in nematic liquid crystals. We believe this is a promising route to controlling colloidal self-assembly in complex media.

### 9:12AM Y47.00003 Control of periodic, quasicrystalline, and arbitrary arrays of liquid crystal defects stabilized by topological colloids and chirality[1] , IVAN SMALYUKH, University of Colorado Boulder — Condensed matter systems with ground-state arrays of defects range from the Abrikosov phases in superconductors, to various blue phases and twist grain boundary phases in liquid crystals, and to skyrmion lattices in chiral ferromagnets. In nematic and chiral nematic liquid crystals, which are true fluids with long-range orientational ordering of constituent anisotropic molecules, point and line defects spontaneously occur as a result of symmetry-breaking phase transitions or due to flow, but they typically annihilate with time and cannot be controlled. This lecture will discuss physical underpinnings of optically patterned and self-assembled two-dimensional arrays of long-term stable point defects and disclination loops bound together by elastic energy-minimizing twisted director structures and/or stabilized by colloids. The topological charge conservation and the interplay of topologies of genus g> 1 particles, fields, and defects provide robust means for controlling three-dimensional textures with arrays of optically- and electrically-reconfigurable defects. In the periodic lattices of defects, we introduce various dislocations (i.e., defects in positional ordering of defects) and use them to generate optical vortices in diffracted laser beams. The lecture will conclude with a discussion of how these findings bridge the studies of defects in condensed matter physics and optics and may enable applications in data storage, singular optics, displays, electro-optic devices, and diffraction gratings.

[1]We acknowledge the support of NSF grants DMR-0820579 and DMR-0847782.

### 9:48AM Y47.00004 Nanoparticles at fluid interfaces: how capping ligands control adsorption, stability and dynamics , VALERIA GARBIN, Imperial College London — The spontaneous assembly of nanoparticles at fluid-fluid interfaces is exploited in microfluidic encapsulation, fabrication of nanomaterials, oil recovery, and catalysis. Control over the microstructure formed by interfacial nanoparticles is an important goal in these contexts: the ability to *reversibly* tune the packing fraction enables for nanomaterials with tunable properties, while control over nanoparticle removal and recycling is desirable for green processes. I will discuss how capping ligands can promote interfacial self-assembly by tuning the interfacial energies of the nanoparticles with the fluids. Ligand-mediated particle interactions at the interface then affect the formation of equilibrium and non-equilibrium two-dimensional phases. Important differences with colloidal interactions in a bulk suspension arise due to the discontinuity in solvent properties at the interface, which cause the ligand brushes to rearrange in asymmetric configurations. I will present experimental results for gold nanoparticles capped with short amphiphilic ligands, which spontaneously adsorb at an oil-water interface. Using pendant drop tensiometry, we measured the surface pressure of the nanoparticle monolayer during adsorption and subsequent compression. In contrast to the commonly observed buckling of solid-like films of interfacial particles, upon compression these nanoparticles are mechanically forced out of the interface and into suspension. Area density measurements by a newly developed optical method reveal that ligand-mediated short-range interparticle repulsion enables desorption upon compression. Brownian dynamics simulations corroborate this picture. Therefore, ligand-mediated interactions also determine the fate of nanoparticle monolayers upon out-of-plane deformation.

### 10:24AM Y47.00005 Resolving Defect Formation and Dynamics of the Smectic-A Mesophase[1] , NASSER MOHIEDDIN ABUKHDEIR, University of Waterloo — The formation and interaction of defects in liquid crystalline (LC) phases are fascinating both from a fundamental and applied perspective. Smectic LC phases, which have both orientational and translational order, exhibit relatively complex defect structures [1] and dynamics compared to lower order nematics (possessing only orientational order). A simple example of this complexity is that smectic disclination dynamics differ from those of nematics due to additional topological constraints imposed by the presence of translational order. A far less simple example is the presence of focal conic defect domains [1] that arise due to smectic elasticity favouring layer curvature over compression/dilation. Direct experimental observation of defect formation and dynamics of the smectic-A mesophase is challenging due to them occurring on the nano-scale. Theoretical approaches have had substantial success, particularly extensions of the tensorial Landau-de Gennes free energy for nematics [2] to smectic order [3]. Modelling dynamics via the time-dependent Landau-Ginzburg equation [4] has been shown to resolve topologically consistent smectic dynamics which agree with experimentally determined phase transition kinetics [5]. This talk will present an overview of recent research in this area, including the effects of an external field. The results of this research support the use of a relatively complex model of smectic dynamics. Specifically, it is shown that couplings between both short- and long-range orientational/translational order play an important role in smectic defect formation and interaction.

[1] Kleman, M. (1982) "Points Lines and Walls"
[2] de Gennes, P. & Prost, J. (1995) "The Physics of Liquid Crystals"
[3] Mukherjee, P. K.; Pleiner, H. & Brand, H. R. (2001) *Eur. Phys. J. E*
[4] Desai, R. C. & Kapral, R. (2009) "Dynamics of Self-Organized and Self-Assembled Structures"
[5] Abukhdeir, N. M. & Rey, A. D. (2008) *New Journal of Physics*

[1]This work was made possible by Natural Sciences and Engineering Research Council of Canada, the facilities of the Shared Hierarchical Academic Research Computing Network, and Compute/Calcul Canada.

## Friday, March 22, 2013 11:15AM - 2:15PM –
Session Z10 DFD DPOLY GSNP: Invited Session: Elastic Instabilities and Pattern Formation in Structureless Solids 309 - Benny Davidovitch, University of Massachusetts Amherst

### 11:15AM Z10.00001 Coarsening of patterns from scale free instabilities in soft solids , EVAN HOHLFELD, University of Massachusetts, Amherst — Soft materials such as rubbery solids have hidden, scale-free instabilities that are undetectable by linearized analysis, yet which have no energy barrier for onset. Examples include the nucleation of sharply creased surface folds resembling the sulci on the brain and the nucleation and growth of cavities. These instabilities can be understood as quasi-phase transitions: they have well defined binodal points, form via a nucleation and growth process, and have finite energies of transformation; however, there is no clear phase boundary dividing the "nucleated phase" from the surrounding elastomer. First anticipated by Weierstrass more than 100 years ago, our understanding of these instabilities—so called "Weierstrass needles"—is now rapidly developing as an increasing number of physical examples are being identified. Recent experimental and theoretical work has continued to deepen the analogy between a Weierstrass needle and a more traditional phase transition. Along this line, I will present new results showing how the coarsening of a crease pattern can be understood as a form of Ostwald ripening. I will also discuss classes of systems which might support other examples of Weierstrass needles.

### 11:51AM Z10.00002 Instabilities in axisymmetrically constrained sheets[1] , JOSÉ BICO, École Supérieure de Physique et de Chimie Indust. de la Ville de Paris — We propose to describe three different situations where a circular sheet is submitted to axisymmetric loads resulting from capillary forces or constrained boundary conditions. In a first case, a thin annulus floating on water is radially compressed by a surface pressure induced by the addition of surfactant molecules outside the annulus. As a consequence the annulus is compressed in the orthoradial direction and wrinkles are observed beyond a critical load. In a second situation, a planar disk is deposited on an adhesive sphere. Can the sheet accommodate the change in gaussian curvature? Wrinkles actually appear at the edge of the disk if the diameter exceeds a critical value. A third experiment finally involves a planar disk squeezed in a spherical mold. While low confinement induces the formation of localized folds, these folds eventually evolve into a cascade of orthoradial wrinkles.

[1]with B. Roman, M. Piñeirua and J. Hure

**12:27PM Z10.00003 The generation of stress-focusing features in confined elastic sheets** , ROBERT SCHROLL, Departamento de Fisica, Universidad de Santiago de Chile — Crumpling is the canonical example of stress focusing in a confined elastic sheet. Subject to a large biaxial confinement, the sheet must bend in multiple directions, which induces Gaussian curvature and therefore strain. This strain is best accommodated by focusing the stress into small regions. In a crumpled sheet, multiple stress-focusing features appear apparently randomly. Here, I present two systems in which stress-focusing features are created in a controlled manner. In the first, a thin sheet is floated on a droplet of water. As the curvature of the droplet is increased, first wrinkles and then a focused features appear on the edge of the sheet. In the second, a focused feature appears at the transition between wrinkle patters of two different wavelengths. The degree of the focusing can be controlled by the confinement, the thickness, and the tension applied transverse to the confinement.

**1:03PM Z10.00004 Compression-triggered instabilities of multi-layer systems: From thin elastic membranes to lipid bilayers on flexible substrates** , HOWARD A. STONE, Department of Mechanical and Aerospace Engineering, Princeton University — Instabilities are triggered when elastic materials are subjected to compression. We explore new features of two distinct systems of this type. First, we describe a two-layer polymeric system under biaxial compressive stress, which exhibits a repetitive wrinkle-to-fold transition that subsequently generates a hierarchical network of folds during reorganization of the stress field. The folds delineate individual domains, and each domain subdivides into smaller ones over multiple generations. By modifying the boundary conditions and geometry, we demonstrate control over the final network morphology. Some analogies to the venation pattern of leaves are indicated. Second, motivated by the confined configurations common to cells, which are wrapped in lipid bilayer membranes, we study a lipid bilayer, coupled to an elastic sheet, and demonstrate that, upon straining, the confined lipid membrane is able to passively regulate its area. In particular, by stretching the elastic support, the bilayer laterally expands without rupture by fusing adhered lipid vesicles; upon compression, lipid tubes grow out of the membrane plane, thus reducing its area. These transformations are reversible, as we show using cycles of expansion and compression, and closely reproduce membrane processes found in cells during area regulation. The two distinct systems illustrate the influence of the substrate on finite amplitude shape changes, for which we describe the time-dependent shape evolution as the stress relaxes. This talk describes joint research with Manouk Abkarian, Marino Arroyo, Pilnam Kim, Mohammad Rahimi and Margarita Staykova.

**1:39PM Z10.00005 Electromechanical instability in soft materials: Theory, experiments and applications** , ZHIGANG SUO, School of Engineering and Applied Sciences, Harvard University — Subject to a voltage, a membrane of a dielectric elastomer reduces thickness and expands area, possibly straining over 100%. The phenomenon is being developed as transducers for broad applications, including soft robots, adaptive optics, Braille displays, and electric generators. The behavior of dielectric elastomers is closely tied to electromechanical instability. This instability may limit the performance of devices, and may also be used to achieve giant actuation strains. This talk reviews the theory of dielectric elastomers, coupling large deformation and electric potential. The theory is developed within the framework of continuum mechanics and thermodynamics. The theory attempts to answer commonly asked questions. How do mechanics and electrostatics work together to generate large deformation? How efficiently can a material convert energy from one form to another? How do molecular processes affect macroscopic behavior? The theory is used to describe electromechanical instability, and is related to recent experiments.

# Friday, March 22, 2013 11:15AM - 12:27PM –
## Session Z32 DFD: Micro/Nanofluidics II 340 - German Drazer, Rutgers University

**11:15AM Z32.00001 Electro-coflow as a means to study whipping instabilities in electrified liquid jets** , JOSEFA GUERRERO MILLAN, Georgia Institute of Technology, VENKAT GUNDABALA, Indian Institute of Technology (IIT) Bombay, ALBERTO FERNANDEZ-NIEVES, Georgia Institute of Technology — Whipping is a non-axisymmetric instability that appears in electrified jets. In air, it usually manifests in a chaotic fashion preventing its detailed experimental characterization. We use electro-coflow to generate a steady-state whipping structure and quantify its wave-like properties, which we understand from simple force balances.

**11:27AM Z32.00002 Do electroviscous effects impact the hydraulic conductance of xylem? A theoretical inquiry**[1] , MICHAEL SANTIAGO, VINAY PAGAY, ABRAHAM STROOCK, Cornell University — Experiments show that the hydraulic conductance of plant xylem (K) varies with the ionic-strength (I) and pH of the sap, a behavior usually attributed to the swelling of hydrogels that cover bordered pits—conduits that interconnect individual xylem vessels. These gels are believed to swell at low I or large pH, and thus decrease the flow cross-section and K. But experiments have shown behaviors that contradict this hypothesis, where a decrease in I serves to increase K. Here, we investigate whether these observations could be explained by electroviscous effects in the pores of bordered pits, since the literature suggests that pits are covered by materials that develop electric charge in aqueous solution, e.g. lignin and pectin. We use experimental measurements from the literature, combined with standard electrokinetic theory, to estimate the electroviscous effect of I and pH on K. We find that K varies non-monotonically with I and can drop to a minimum of 0.8 of its maximum value, and that our predictions fit the available experimental data for physiologically relevant conditions in I and pH. We conclude that electrokinetics could explain, at least partially, the observed changes in K, and propose experiments to test this hypothesis.

[1]This material is based upon work supported by the National Science Foundation Graduate Research Fellowship under Grant No. DGE 1144153.

**11:39AM Z32.00003 Microfluidic route to generation of celloidosomes** , VENKATA GUNDABALA, SERGIO MARTINEZ-ESCOBAR, School of Physics, Georgia Institute of Technology, Atlanta, USA, SAMANTHA MARQUEZ, Maggie L. Walker Governor's School for Government and Internation al Studies, Richmond, VA, USA, MANUEL MARQUEZ, YNano LLC, 14148 Riverdowns South Dr., Midlothian, Virginia 23113-3796, USA, ALBERTO FERNANDEZ-NIEVES, School of Physics, Georgia Institute of Technology, Atlanta, USA, MICROFLUIDICS TEAM — Here we present a microfluidic method to generate alginate particles with a liquid core and a shell with yeast cells encapsulated in it. This particular class of celloidosomes with cells embedded into the thin shell region at the surface, allows for easy access of oxygen to the cells improving their viability. The liquid core opens the possibility of encapsulating multiple types of cells into the core and the shell. The microfluidic method involving double emulsion technology employed here ensures robust control over the size of the particles and density of the encapsulated cells. The study has shown that the stability of the inner core is very much dependent on the viscosity of the oil used for collecting the emulsion.

### 11:51AM Z32.00004 Dynamics assembly of magnetic microparticles suspended in moving droplets under the influence of magnetic fields[1] , HELMUT STREY, ERIC BROUZES, TRAVIS KRUSE, Stony Brook University — Droplet microfluidics has experienced tremendous growth, particularly since it is well suited for single-cell manipulation and analysis. As mature methods for high throughput droplet manipulation have been developed a technological bottleneck of current droplet microfluidics is that because droplets are separated, sequential chemical reactions are more difficult to achieve. For example, it is very difficult to concentrate target molecules, especially since every reaction step adds volume to the droplets. Our solution to this problem is to employ functionalized magnetic beads inside droplets. The basic idea is that an external magnetic field could be used to concentrate the magnetic beads in one part of the droplet and those could then be extracted by splitting the droplet. Here we present an experimental study of the self-assembly of superparamagnetic microparticles that are suspended in moving droplets and experience a combination of forces due to the internal fluid flow fields and external magnetic fields. We observed that this interplay of flow fields coupled to the formation of particle assemblies leads to the formations of stable patterns depending on the flow speed and magnetic field strength. An understanding of this dynamic assembly is critical in employing external forces for applications in separation and sorting.

[1]funding through NYSTAR, Center for Advanced Technology and a grant from NIH-NHGRI (1 R21 HG006206-01).

### 12:03PM Z32.00005 Droplet pairing and coalescence control for generation of combinatorial signals , EUJIN UM, Princeton University, MATTHEW ROGERS, Firmenich Inc., HOWARD STONE, Princeton University — A co-flowing aqueous phase with an immiscible oil phase in a microchannel generates uniformly spaced, monodisperse droplets, which retain their shape by not touching each other or by being stabilized with surfactants at the oil-water interface. However, droplet coalescence is required in many advanced applications, which can be achieved by a complex channel geometry or size differences in the droplets, and as well as by procedures to reduce the effect of a surfactant. These approaches, again, hinder the stability of droplets further downstream. We designed a microchannel which consistently inserts gas-bubble between droplets so that pairing and coalescence of droplets occurs even in the presence of surfactant, and yet prevents unwanted merging with other droplets. Aqueous droplets placed between the bubbles alter their relative speeds and spacing, and consequently we study the change in the number of droplet pairings in relation to the characteristics of the bubbles and the volume of aqueous droplets. By integrating this approach with droplets of different materials, we can program the output sequence of droplet compositions, and such complex combinatorial signals generated are aimed for concentration gradient generation and dynamic stimulation of biological cells with chemicals.

### 12:15PM Z32.00006 Microfluidic Printing and Ablation of Metallic Films by Modulated Capillary and Maxwell Stresses , GERRY DELLA ROCCA, SANDRA TROIAN, California Institute of Technology, MC 128-95, Pasadena, CA 91125 — Liquid dosing strategies for micro/nanofluidic applications normally rely on interior flow driven by external pressure gradients. To maintain a constant flow rate, the effective pressure drop over a given length conduit must scale inversely as the fourth power in the conduit radius, as prescribed by the Hagen-Poiseuille relation. For micron or nanoscale capillaries, this constraint requires enormous pressure gradients and external control mechanisms. This burden, coupled with the likelihood of occlusions due to gas bubbles, contaminants or carrier particles, limits the usefulness of internal flow strategies for applications involving emission of charged droplets or ions. In this talk, we focus on capillary flow in slender V grooves as a more robust and self-regulating fluidic delivery system. When coupled with spatiotemporal modulation of Maxwell stresses induced by an external electric field, beams of droplets or ions can be metered reliably and effectively. Here we explore the steady state, transient and oscillatory flow characteristics of microscale metallic films in V-grooves subject to capillary and Maxwell stresses. The geometry investigated will focus on printing and ion ablation of thin films for electronic circuits and photovoltaic displays.