The Twenty-Sixth Annual Student Research Symposium in Memory of Professor Stephan Berko

Brandeis University, Physics Building, Abelson 131
Monday, May 15, 2017, 9:00 am-12:00pm

8:45-9:00 **Refreshments**

9:00-9:52 **Session 1: Moderator – Mike Hagan**

Raunak Sakhardande *"Microstructures in a phase separating chiral membrane"*
Gabe Bronk *"The Physics of Life and Death: The Pairing of DNA Sequences during Homologous Recombination"*
Joanna Robaszewski *"Assembling vesicles with filamentous viruses"*
Joia Miller *"Conformationally-tunable interactions of rafts in colloidal membranes"*

9:52-10:06 **Coffee Break**

10:06-10:45 **Session 2: Moderator – David Roberts**

Jetin Thomas *"Exploring the phase space of dense suspensions undergoing shear thickening"*
David Dodsworth *"A Search for Supersymmetric Top Quarks"*
Kelsey O'Connor *"How to Find a Fake"*

10:45-12:00 **The Berko Awards, presented by John Wardle and the Faculty Advisers**

Micah Margolis* *"Modeling the Jet of Quasar 3C 273: Adding Faraday Effects"*
Caleb Wagner *"Two-way diffusion equations and stationary distributions of active particles"*
Farri Mohajerani *"Polymorphic icosahedral shells assembling around many cargo molecules"*

12:00 **Buffet lunch served in the lounge (Room 333)**

*undergraduate honors degree candidate

2017 Berko Student Research Symposium: ABSTRACTS

Gabe Bronk – *"The Physics of Life and Death: The Pairing of DNA Sequences during Homologous Recombination"*
DNA constantly undergoes double-strand breaks (DSBs) due to ionizing radiation, certain chemicals, and malfunctions in replication and transcription. Cell death ensues if the DSB is not repaired. Homologous recombination is a major pathway by which DSBs are repaired, and this pathway involves the broken chromosomal region hybridizing with complimentary DNA at another locus. How is it that the broken region hybridizes with the complimentary sequence rather than one of the myriad other DNA sequences in the genome? To answer this question, we induce a DSB at a particular site in haploid *S. cerevisiae*, and we measure the repair efficiency in different strains containing different amounts of complementarity between the broken locus and a homologous donor locus. We find that the repair efficiency is a monotonically decreasing function of the number of mismatches. To reveal the mechanism of recognition of the complementary DNA, we compare the *in vivo* data to a thermodynamic model, and we find that the predicted repair efficiencies agree quantitatively with the experimental data. This indicates that the simple thermodynamics of DNA/protein annealing dictates the extent of complementary DNA recognition and thus the likelihood of cell survival. An alternative hypothesis, a first-passage model of DNA annealing, seems to only explain the data in a limited regime, but additional experiments are being conducted to further test these two models.

David Dodsworth – "A Search for Supersymmetric Top Quarks"
The standard model, a theory describing all the fundamental particles of nature and their interactions, was completed with the discovery of the Higgs boson in 2012. Yet, many questions are left unanswered: Why is the Higgs mass relatively small? Why can neutrinos oscillate between flavors? What is dark matter? These outstanding problems have a potential solution in the form of supersymmetry, a set of theories that posit the existence of a boson-fermion symmetry and a corresponding super-partner to every particle contained in the standard model. A search for one such particle, the supersymmetric top (stop), will be discussed, outlining methods and variables used to discriminate this relatively rare theorized production in the presence of much larger QCD backgrounds.

Micah Margolis – *"Modeling the Jet of Quasar 3C 273: Adding Faraday Effects"*
In this study we expanded J. Mizrahi's (2007) model for the magnetic field of the jet of the quasar 3C 273 by considering Faraday Effects. Due to the complexity of the equations from adding Faraday Effects, we were limited to using a jet-frame viewing angle = 90 degrees. The model was motivated by observations from T. Chen (2005), and the results were fit to the constraints of the data. The model predicted similar total emission, fractional polarization, and depolarization profiles to the observations. We were able to use the model to estimate the strength of the magnetic field, the relative strength of the toroidal and longitudinal field components, and the thermal and relativistic electron densities.

Joia Miller – "Conformationally-tunable interactions of rafts in colloidal membranes"
Colloidal membranes composed of micron-long rods are a rich system for studying membrane properties. Specifically, we study membrane-mediated interactions between self-assembled rafts of shorter rods suspended in the membrane. These rafts are made up of chiral rods and display strongly repulsive interactions when in a background membrane of the opposite chirality. However, we find that lowering the net chirality of the membrane allows rafts to bind together into groups by stabilizing an alternate raft state with unfavorable internal twist that minimizes membrane deformation.

Farri Mohajerani – *"Polymorphic icosahedral shells assembling around many cargo molecules"*
Bacterial microcompartments (BMCs) are large icosahedral shells that sequester the enzymes and reactants responsible for particular metabolic pathways in bacteria. Although different BMCs vary in size and encapsulate different cargoes, they are constructed from similar pentameric and hexameric shell proteins. Despite recent groundbreaking experiments which visualized the formation of individual BMCs, the detailed assembly pathways and the factors which control shell size remain unclear. We have developed theoretical and computational models that describe the dynamical encapsulation of hundreds of cargo molecules by self-assembling icosahedral shells. We present phase diagrams and analysis of dynamical simulation trajectories showing how the thermodynamics, assembly pathways, and emergent structures depend on the interactions among shell proteins and cargo molecules. Our model suggests a mechanism for controlling insertion of the 12 pentamers required for a closed shell topology, and the relationship between assembly pathway and BMC size polydispersity.

Kelsey O'Connor – "*How to Find a Fake"*
A search for sterile neutrinos with masses less than the W mass is being conducted at the LHC. This "low mass" search presents a number of interesting challenges, including the need for a comprehensive and robust fake background estimation method. A preliminary study of the applicability of the Matrix Method to the fake background estimation has been conducted. The preliminary study shows that the background estimation is significantly improved by including the background estimated with this method.

Joanna Robaszewski -- *"Assembling vesicles with filamentous viruses"*
In the presence of a depletant, liquid crystal-like viruses will assemble into one of several different microscale structures, including tactoids, twisted ribbons, and single layer membranes. The stable structure is readily controlled by the virus and depletant concentrations. Membrane theory predicts that at a critical radius, the membrane configuration becomes unstable and a vesicle becomes the preferred structure; however, vesicles have not been observed using conventional methods. We are able to use genetic engineering to alter the physical properties of the viruses and stabilize vesicle formation. We are studying the membrane to vesicle transition using various microscopy techniques, including confocal microscopy. These phage-based structures can also serve as microscale model systems for biological membranes and vesicles, giving us insight into the physical mechanisms governing membrane deformation.

Raunak Sakhardande – *"Microstructures in a phase separating chiral membrane"*
Chiral rodlike particles suspended in the presence of non-adsorbing polymer are driven by depletion interactions to form diverse high-order assemblies. Of particular interest are colloidal membranes, which is a one rod-length-thick monolayer of vertically aligned rods. Here, we discuss the phase behavior of colloidal membranes comprised of three rod species. One has a short length and right-handed chirality, the other two have long lengths and respectively right- and left-handed chirality. Experiments have shown that such a system undergoes microphase separation, with the short rods forming finite-sized domains floating in a background of the two long species. Tuning the background composition to be effectively achiral leads to complex, non-pairwise interactions between domains which exhibit multiple stable minima. We employ a Ginzburg-Landau description of the system to understand how this behavior depends on chirality and depletion interaction strength, and identify competing interactions which give rise to the complex inter-domain potentials.

Jetin Thomas – *"Exploring the phase space of dense suspensions undergoing shear thickening"*
Dense Suspensions like 'oobleck' display shear thickening (an increase in viscosity) as the confining stress (σ) or strain rate (γ') are increased. Recent studies have clearly shown that increasing number of frictional contacts between suspended particles are responsible for this thickening. Therefore, it is useful to numerically study suspensions at high densities (ϕ) where the probability of making contacts is higher. The forces at the particle scale in suspensions are either hydrodynamically mediated frictionless forces, or frictional contact forces. The forces become predominantly frictional on approaching the shear thickened state. This evolution is well characterized by a graphical representation of the forces within the system called "force tiles". Since, the magnitude of the lubrication forces are much smaller compared to contact forces, these are seen as closely spaced vertices in the tiling, appearing as 'clumps'. This clumping be- comes more pronounced as the stress and density is increased. Using a "density based analysis" of these force tiles, we find a crossover between the low viscosity and high viscosity phase. We find an emerging anisotropy in the pair correlation function and structure factor due to the imposed strain. There is a clear change in symmetry of these correlations with increasing density, indicating a much richer phase diagram.

Caleb Wagner – *"Two-way diffusion equations and stationary distributions of active particles"*
I will be discussing a technique for obtaining the exact steady-state distributions of non-interacting self-propelled particles in a variety of scenarios. These steady-state distributions are shown to be solutions of a type of non-standard PDE called "two-way diffusion" equations, which appear in diverse physical scenarios, including neutron scattering, certain fluid dynamical boundary flows, and acceleration of particles around astrophysical shocks. A novel technique is developed for solving equations of this type, and applied in depth to the case of self-propelled particles. Various intriguing non-equilibrium behaviors of self-propelled particles are explored using the resulting steady-state solutions.